Avoiding CT Pitfalls

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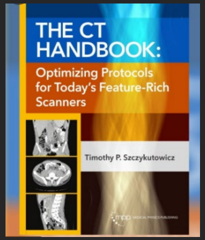
Biomedical Engineering[3]

- # Tim Stick's Disclosures
  - Funds or equipment to UW-Madison
    - Supplies CT protocols to GE Healthcare under a licensing agreement
    - Research support from GE Healthcare
    - Receives research support from Canon Medical Systems USA
  - Personal
    - Medical Advisory Board of iMALOGIX LLC
    - Consult to ALARA Imaging LLC.
    - Licensing Patent US10957444B2 (repeat rates) to Qaelum.
    - Royalties from Medical Physics Publishing
    - Founder of RadUnity Corp.

No personal $ from GE/Canon

RadUnity

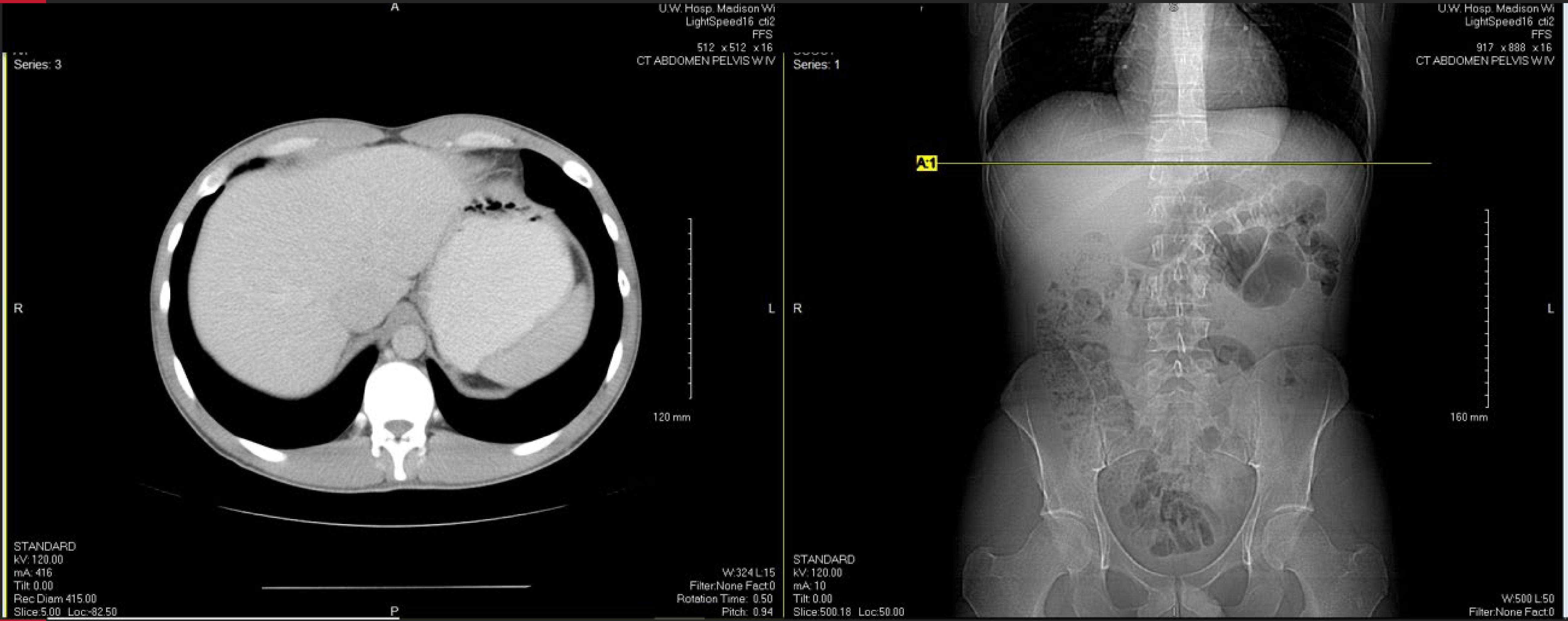


Learning Objectives

- Learn how evolving technology requires rethinking protocol design—legacy practices can reduce diagnostic utility.
- Understand how poor patient positioning, especially in MSK imaging, can degrade image quality.
- Identify and avoid well-meaning but misguided “dose reduction” decisions in pediatrics and pregnancy.

Poor protocol translation

~12 years ago… your truly got a CT scan (negative, dx was stress induced abdominal pains, post-doc/residency/baby…)



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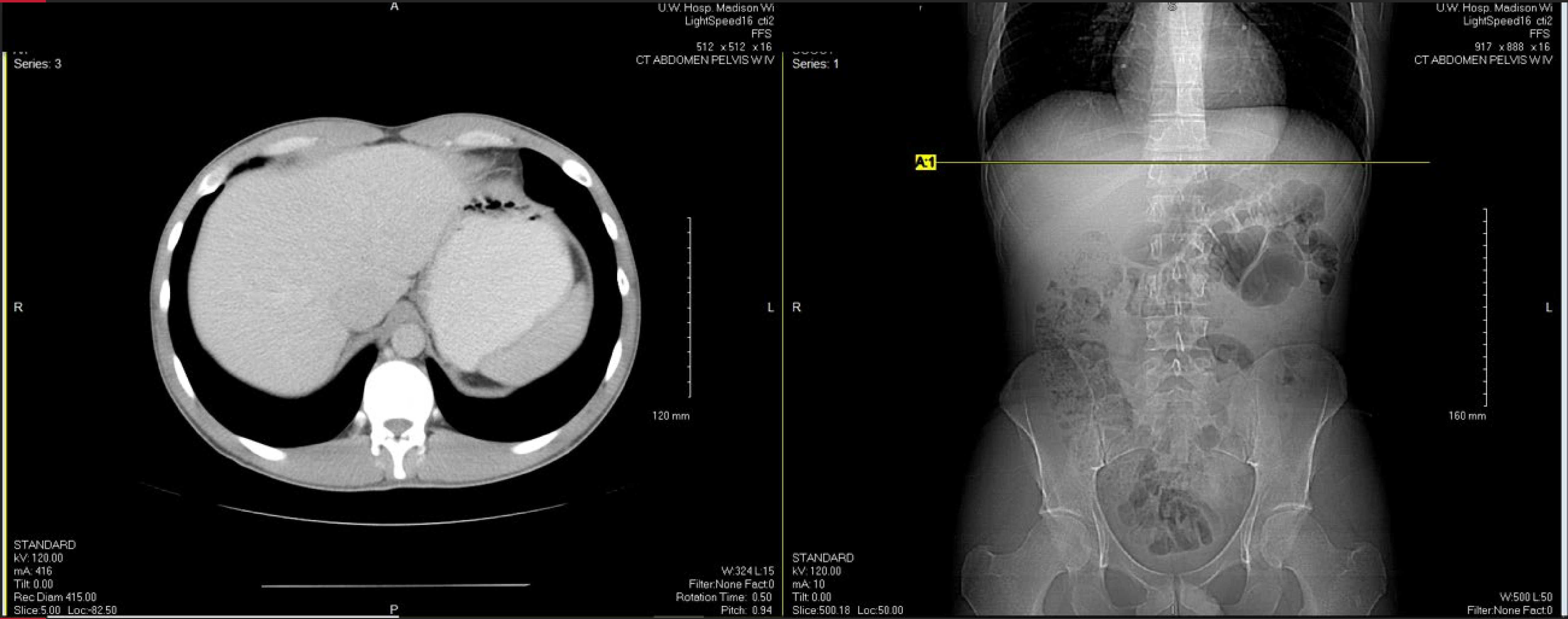


GE Healthcare LS 16 (older scanner even at that time, 32 channel scanner when there were 320 slices…)
Collimation used here was 20 mm (the best this old scanner could do)
Rotation time was 0.5 seconds (not bad)
Pitch was 0.94:1

$$\text{Speed} = \frac{\text{pitch}*\text{collimation}}{\text{Rotation time}}$$

Speed = 0.94:1*20 mm/0.5 s
Speed = 37.6 mm/s

Scan length was ~480 mm

So scan duration was 480 mm / (37.6 mm/s) = 12.8 seconds

Patient [redacted]
Accessi[redacted]
Patient [redacted] LightSpeed16
Exam Description: CT ABDOMEN PELVIS W IV

Dose Report

Series	Type	Scan Range (mm)	CTDIvol (mGy)	DLP (mGy-cm)	Phantom cm
1	Scout	-	-	-	-
200	Axial	I68.750-I68.750	20.83	20.80	Body 32
2	Helical	I4.500-I475.125	17.57	879.96	Body 32
			Total Exam DLP:	900.76	

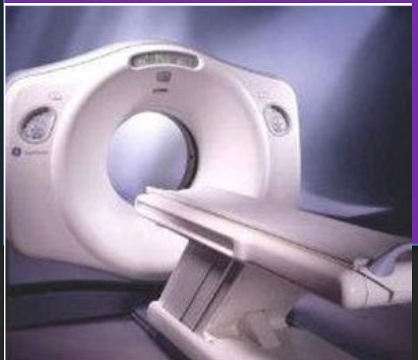
1/1

Highest tube current was 440 mA over pelvis

Old Scanner Exam Settings and outcomes

Collimation: 20 mm
Rotation time: 0.5 s
Pitch: 0.94:1
Max tube current: 440 mA

Scan Duration: 12.8 seconds
CTDIvol: 17.57 mGy



(LightSpeed 16) Old Scanner Exam Settings and outcomes

Collimation: 20 mm
Rotation time: 0.5 s
Pitch: 0.94:1
Max tube current: 440 mA

Scan Duration: 12.8 seconds
CTDIvol: 17.57 mGy

(HD 750) New Scanner Exam Settings and possible outcomes

Collimation: 20 mm
Rotation time: 0.5 s
Pitch: 0.969:1
Max tube current: 440 mA

Scan Duration: ~12 seconds
CTDIvol: ~18 mGy

Direct Translation HD 750 Protocol

Collimation: 20 mm
Rotation time: 0.5 s
Pitch: 0.969:1
Max tube current: ~440 mA

Scan Duration: ~12 seconds
CTDIvol: ~18 mGy

Better HD 750 Protocol

Collimation: 40 mm
Rotation time: 0.4 s
Pitch: 0.984:1
Max tube current: 835 mA

Scan Duration: ~5 seconds
CTDIvol: ~18 mGy

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Original Research | Cardiothoracic Imaging | February 25, 2025

Derivation of Best-Practice Scan Speeds and Excess Scan Durations for CT Pulmonary Angiography: Analysis Using Registry Data for 166,769 Examinations Across 121 Sites

Authors: Yifei Wang, PhD, Carly Stewart, MHA, Rebecca Smith-Bindman, MD, and Timothy P. Szczykutowicz, PhD | AUTHOR INFO & AFFILIATIONS

Volume 224, Issue 4 | https://doi.org/10.2214/AJR.24.32323

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I designed a study to see how often this kind of poor protocol translation is occurring

$$Excess\ Scan\ Duration\ [s] = max\left(0, \frac{Scan\ Length\ [mm]}{Observed\ Scan\ Speed\ [mm/s]} - \frac{Scan\ Length\ [mm]}{Best{-}Practice\ Scan\ Speed\ [mm/s]}\right),$$

In this study, we used 166,769 CTPA examinations from an international dose registry to determine best-practice scan speeds for combinations of scanner model and radiation dose categories, based on actual 95th-percentile speeds. The scan speed was slower than the best-practice scan speed for 87% of acquisitions, and ≥20% slower for 62% of acquisitions. Use of the best-practice scan speed could have saved a median of 1.2 seconds and a mean of 2.3 seconds in comparison with a median actual scan duration of 4.8 seconds.

Turns out it is occurring a lot

@Prof_TimStick's Actionable information

- You can get away with blindly copy/paste most CT protocol clinical instructions (patient prep, IV contrast, breathing instructions, oral contrast, etc.) but when switching to a new scanner **almost always** should involve a change to acquisition parameter

PE scanning in pregnancy (breast dose, PE CT vs VQ)

ARTICLE

Ferrata Storti Foundation

Computed tomography pulmonary angiography *versus* ventilation-perfusion lung scanning for diagnosing pulmonary embolism during pregnancy: a systematic review and meta-analysis

Haematologica 2019
Volume 104(1):176-188

Cécile Tromeur,[1,2,3] Liselotte M. van der Pol,[1,4] Pierre-Yves Le Roux,[5] Yvonne Ende-Verhaar,[1] Pierre-Yves Salaun,[5] Christophe Leroyer,[2,3] Francis Couturaud,[2,3] Lucia J.M. Kroft,[6] Menno V. Huisman[1] and Frederikus A. Klok[1]

[1]Department of Thrombosis and Hemostasis, Leiden University Medical Center, the Netherlands; [2]Groupe d'Etude de la Thrombose de Bretagne Occidentale, University of Brest, Equipe d'Accueil 3878, Department of Internal Medicine and Chest Diseases, CHRU Brest, France; [3]Centre d'Investigation Clinique INSERM 1412, University of Brest, France; [4]Department of Internal Medicine, Haga Teaching Hospital, the Hague, the Netherlands;

rently used. The higher breast radiation exposure with CTPA partly explains the recommendation of V-Q lung scans by international guidelines for pregnant patients with suspected PE. The Society of Thoracic Radiology clinical practice guidelines have presented comparable radiation exposure doses to our findings.[74] However, since

...ong the studies prevents a solid evaluation of the sensi-ity. Moreover, radiation doses associated with CTPA and V-Q lung scanning are well below the safety threshold.

ARTICLE

Coagulation & its Disorders

Ferrata Storti Foundation

Computed tomography pulmonary angiography *versus* ventilation-perfusion lung scanning for diagnosing pulmonary embolism during pregnancy: a systematic review and meta-analysis

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Dose Metric	CTPA	V-Q
Maternal Effective dose (mSv)	0.23-9.7	0.9-5.85
Fetal absorbed dose (mGy)	0.002-0.51	0.2-0.7
DLP (mGy*cm)	69-397	n/a

Fetus	No data	There is no data from humans on a dose threshold for prenatal death, microcephaly, or childhood cancer. ICRP Publication 90 [24] discusses these effects in more detail; some have been shown in animal models.
Fetus	0.3 Gy delivered 8–15 weeks post conception	During this window of cortical sensitivity, severe mental retardation was found in atomic bomb survivors. A radiation dose of 1 Gy would increase the risk for severe mental retardation by 40%.
Fetus	25 IQ point reduction per 1 Gy during weeks 8–15 post conception	Linear trend observed with atomic bomb survivors, but below 0.1 Gy the IQ reduction was not statistically significant.
Fetus	0.2 Gy delivered 1–8 weeks post conception	Atomic bomb survivors receiving more than this level of dose were smaller (2–3 cm in height and 1 cm head circumference) and lighter (3 kg) relative to controls. Note: this finding was not reported in the executive summary of ICRP Publication 90, but was in the report body.
Fetus	0.25 Gy delivered 2–8 weeks post conception	Organ malformation

“The CT Handbook: Optimizing Protocols for Today’s feature-rich scanners”
By Tim Szczykutowicz. Medical Physics Publishing 2020

The last slide says fetal dose is < 1 mGy from CTPA and V-Q

So we just need to give 200+ scans to reach the smallest threshold observed in atomic bomb survivors

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Fetus	0.25 Gy delivered 2–8 weeks post conception	Organ malformation

Pregnant PE patient things to avoid

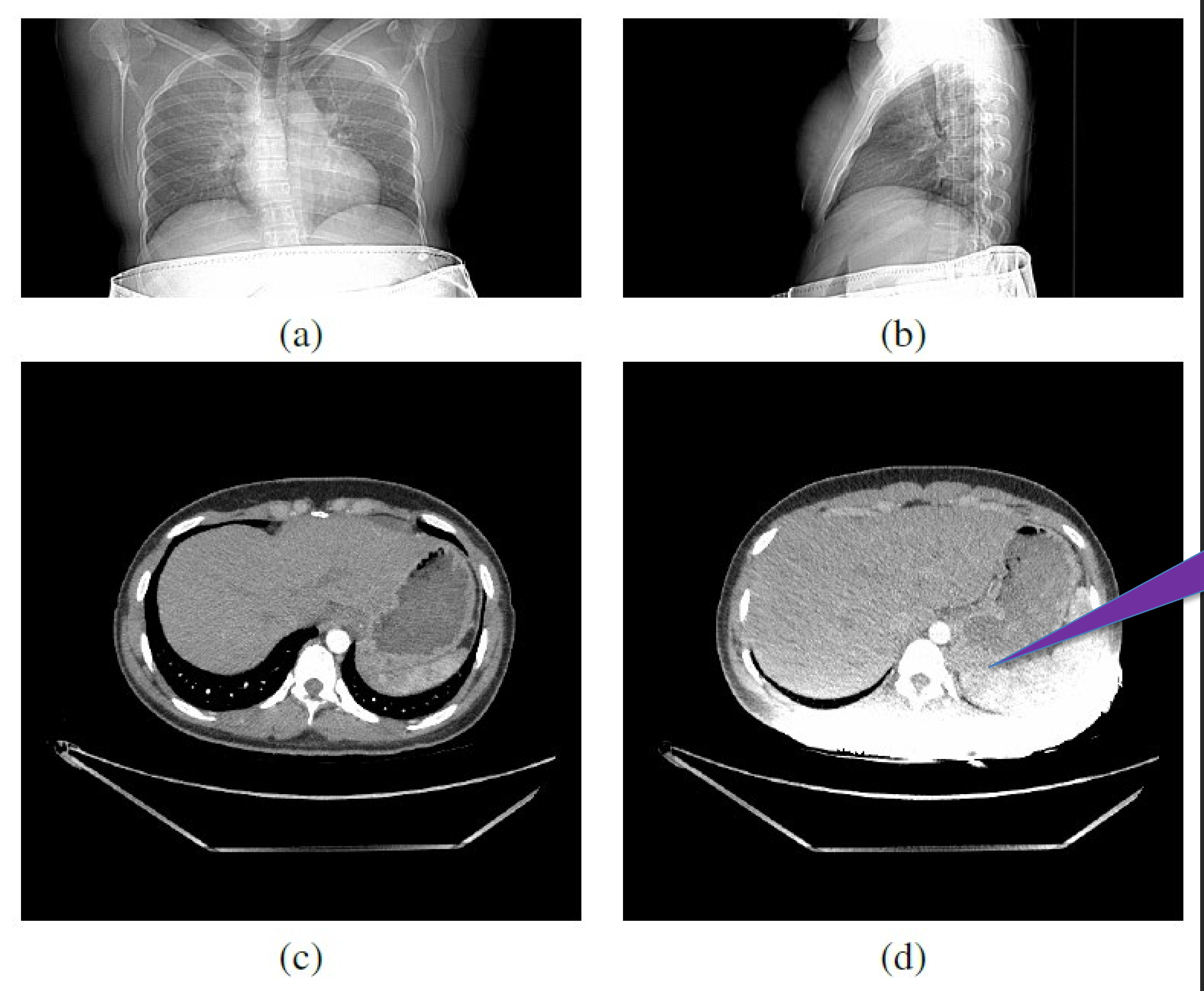
Doing any of these things limits diagnostic utility or limits the robustness of the protocol.

PE is the leading cause of maternal death!

1. Don’t limit scan coverage to not include the lung bases.
2. Don’t reduce dose (lower mAs).
3. Don’t skip doing timing bolus/bolus tracking.
4. Don’t put a shield on unless you have to by law or the patient asks (peace of mind).
    1. If you put a shield on, put it FAR away from the lung bases.
    2. Watch to make sure the shield doesn’t slip down over the lungs.
5. Don’t have them drink barium! Why waste time? The fetus does is already hundreds of times below any level where data shows there could be an issue.

Question the literature. Methods producing huge fetal dose reductions don’t really mean anything when the starting dose is already a hundred times below limits we care about…

Yuck, IQ resulting from a shield slipping down into scan range ☹



Tech included lead apron in scan range (or apron slipped during scan)

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NUMBER 4

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Patient Shielding in Diagnostic Imaging: Discontinuing a Legacy Practice

Rebecca M. Marsh[1] and Michael Silosky[1]

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US law in 1976 when we thought x-rays caused hereditary risks

Shields cause increases in repeated imaging

Shields decrease diagnostic utility of images via artifacts

Shields cause increases in patient dose in some cases

Examples of Radiation-Based Superheroes:

The Hulk:

Bruce Banner becomes the Hulk after being caught in a gamma bomb explosion.

Captain Atom:

In the DC Comics universe, Captain Atom was vaporized by a thermonuclear explosion, only to be rebuilt as a being of pure energy.

Firestorm:

This character's powers are linked to a nuclear accident, allowing him to manipulate matter and energy.

Daredevil:

In some versions, Daredevil's blindness and enhanced senses result from an accident involving radioactive waste.

Spider-Man:

A radioactive spider bite gives Spider-Man his powers, including super strength, agility, and the ability to stick to walls.

Black Canary:

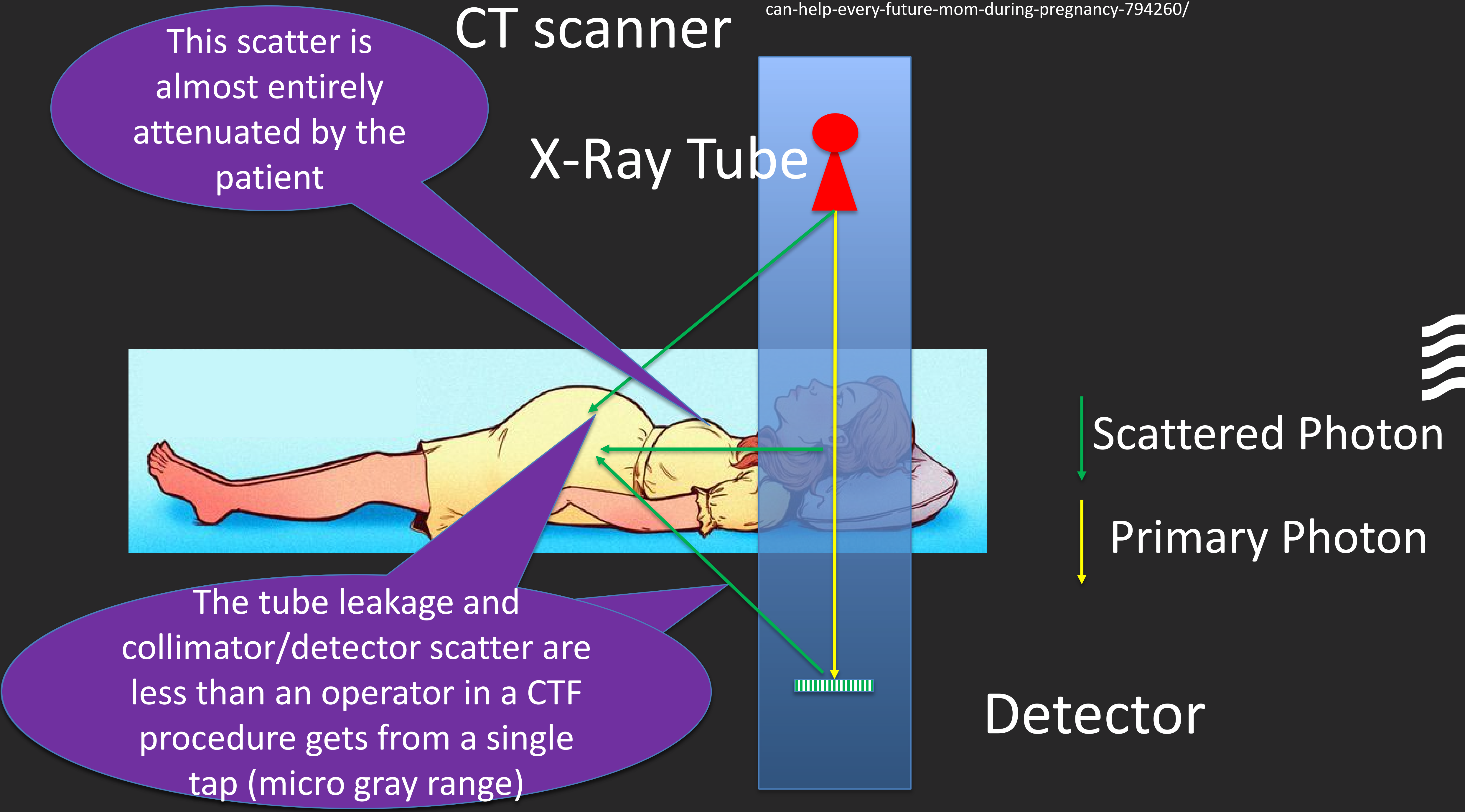
Some comic book storylines give her the "Super-Scream" ability due to radiation exposure.

Head scanning in pregnancy, fetal dose

Scan Region	$CTDI_{vol}$ (mGy) Required to Give Uterus Dose of 50–100 mGy	Median Dose for This Scan Type	Number of Scans Needed to Exceed 50/100 mGy Threshold	Scan Range Limits
Abdominal and thoracic Imaging				
Abdomen Pelvis	36/72	12	3/6	Top of diaphragm to pubic symphysis
Pelvis	36/72	13	3/5.5	Top of iliac crests to pubic symphysis
Chest	>100	11	>100	Lung apices to lung bases
Neuro Imaging				
Brain	>100	49	>100	
Neck	>100	15	>100	
Thoracic Spine	>100	23	>100	Top of C7 to the bottom of L1
Lumbar Spine	38/76	25	1.5/3	Top of T12 to the bottom of S2

CT scanner

Image adapted from https://brightside.me/inspiration-family-and-kids/3-safe-positions-that-can-help-every-future-mom-during-pregnancy-794260/

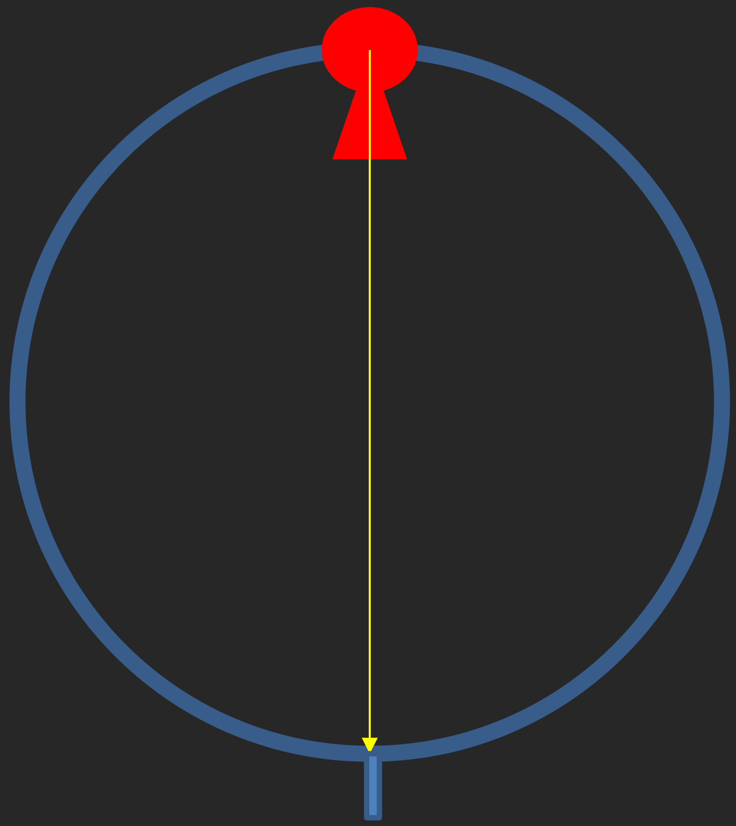


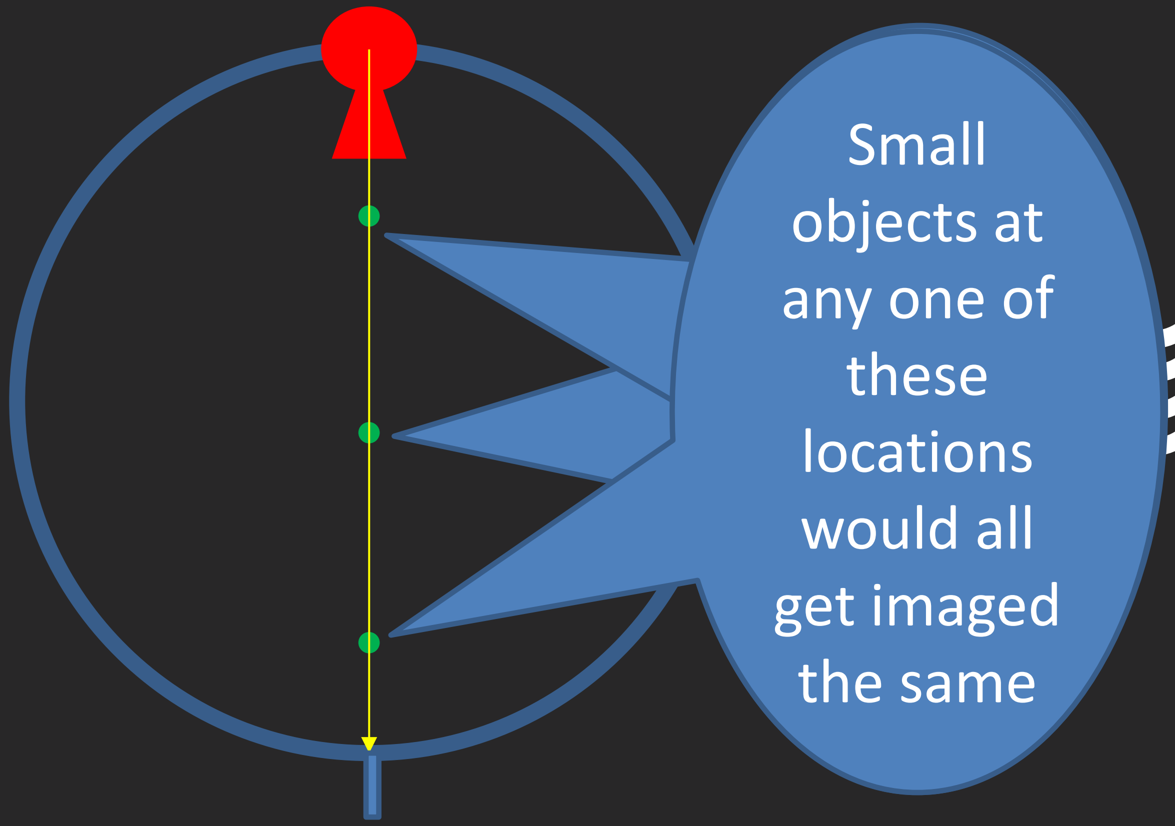
Head Scanning with Lead, possible issues

- If lead is used over the torso during a head scan, it may
  - Interfere with a bolus tracking scan if the head scan is a CTA
    - E.g., our Head CTA performs bolus tracking over the arch
  - Take time to place. Where minutes count in the setting of acute stroke, explain why a Pb apron is being used and placing/removing takes time.
  - Slide up the patient (given their pregnant body habitus) and interfere with any head scanning that includes the neck region

Patient positioning for high spatial resolution

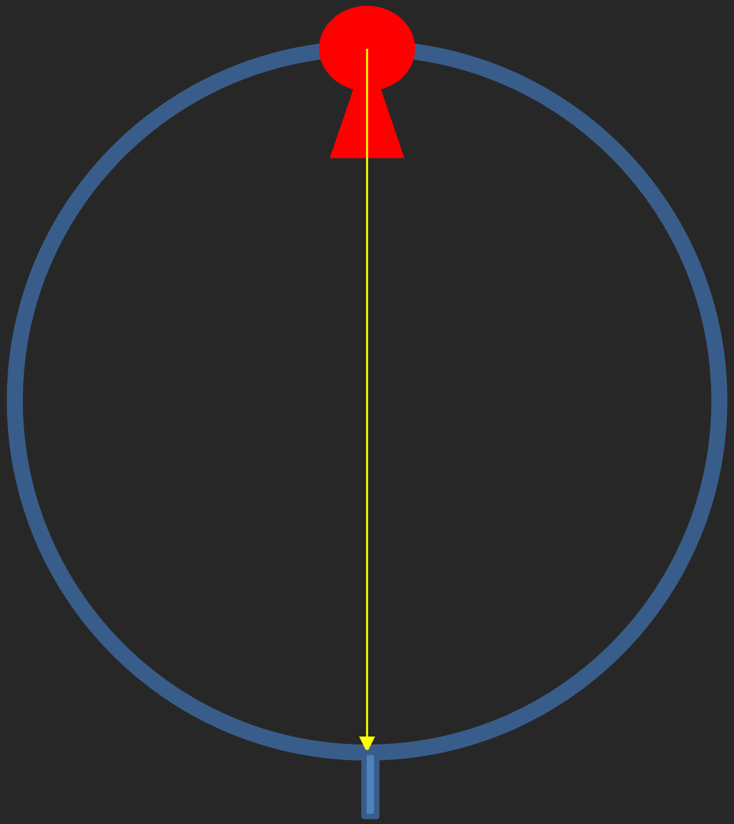
Position and Spatial Resolution

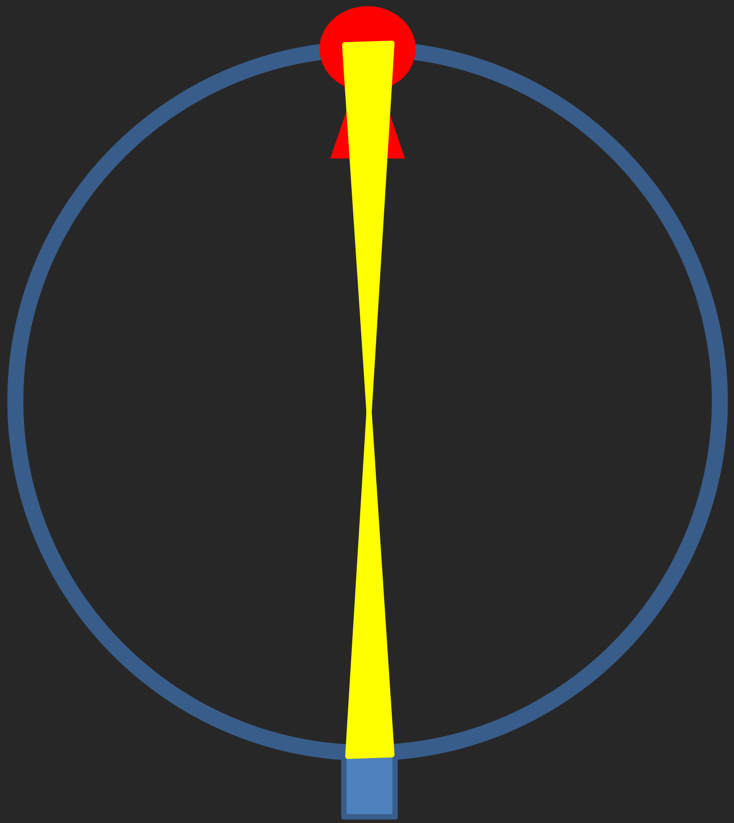




Ideally we would have a focal spot size of zero, a detector size of zero, and a data acquisition time of zero

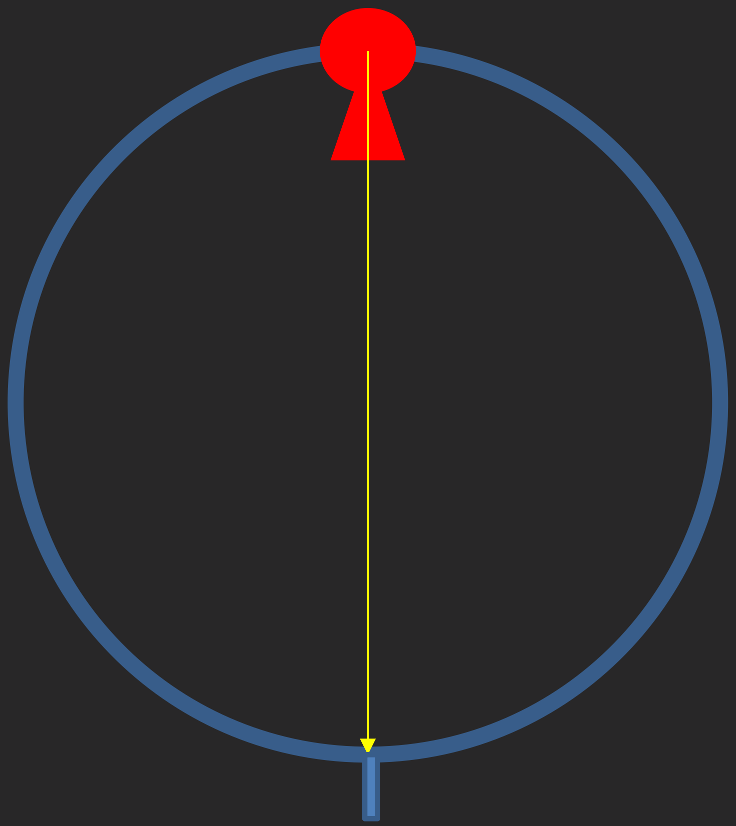
Position and Spatial Resolution

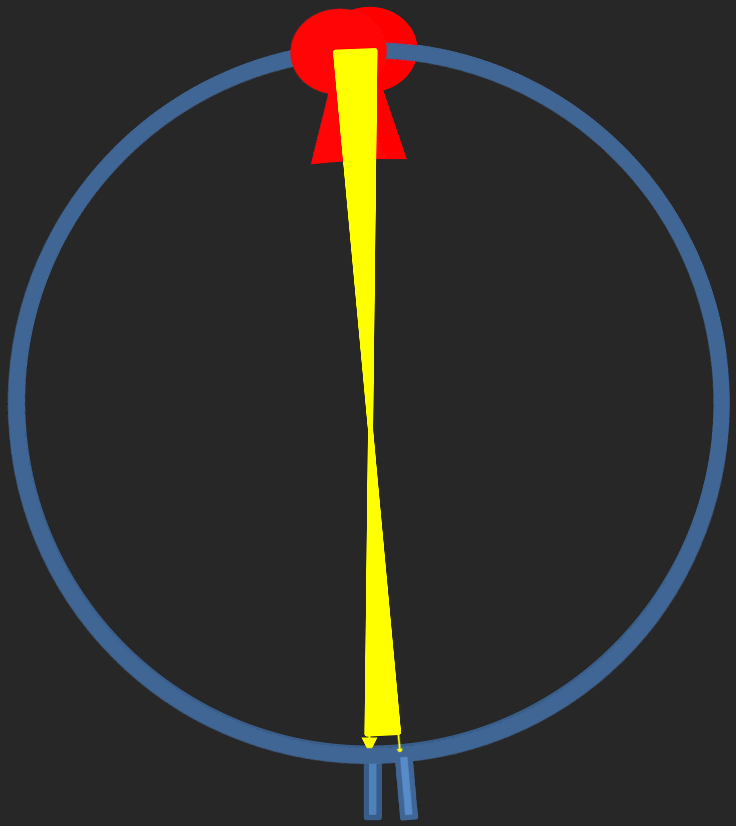




The finite size of the focal spot and detector element work together to blur our images when one moves closer to the focal spot or detector

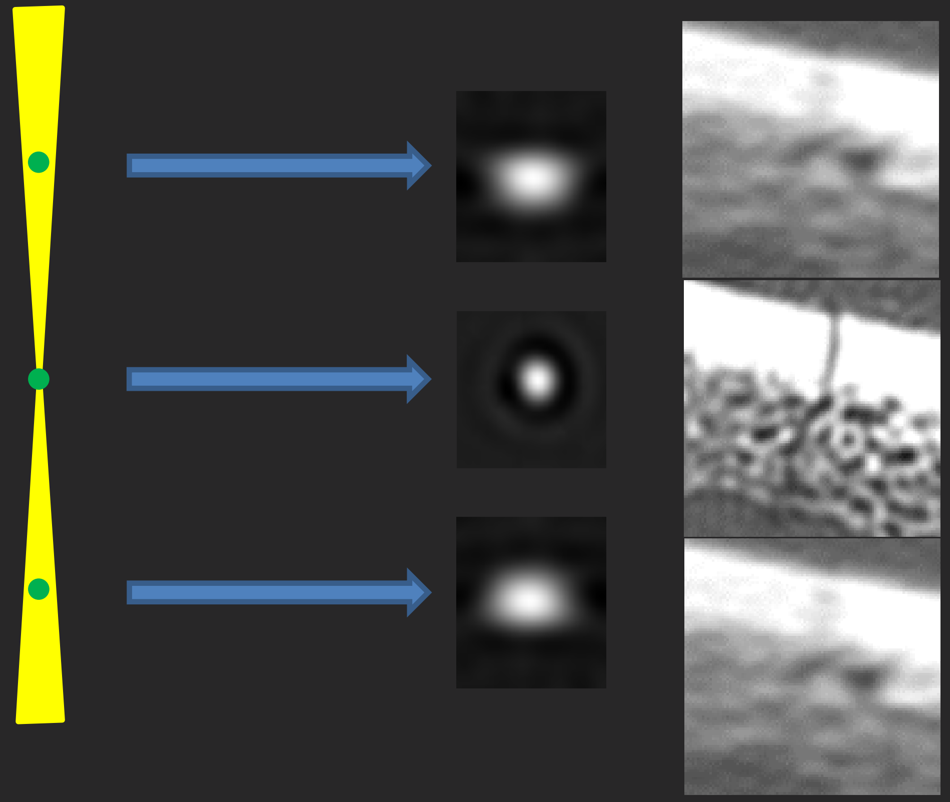
Position and Spatial Resolution



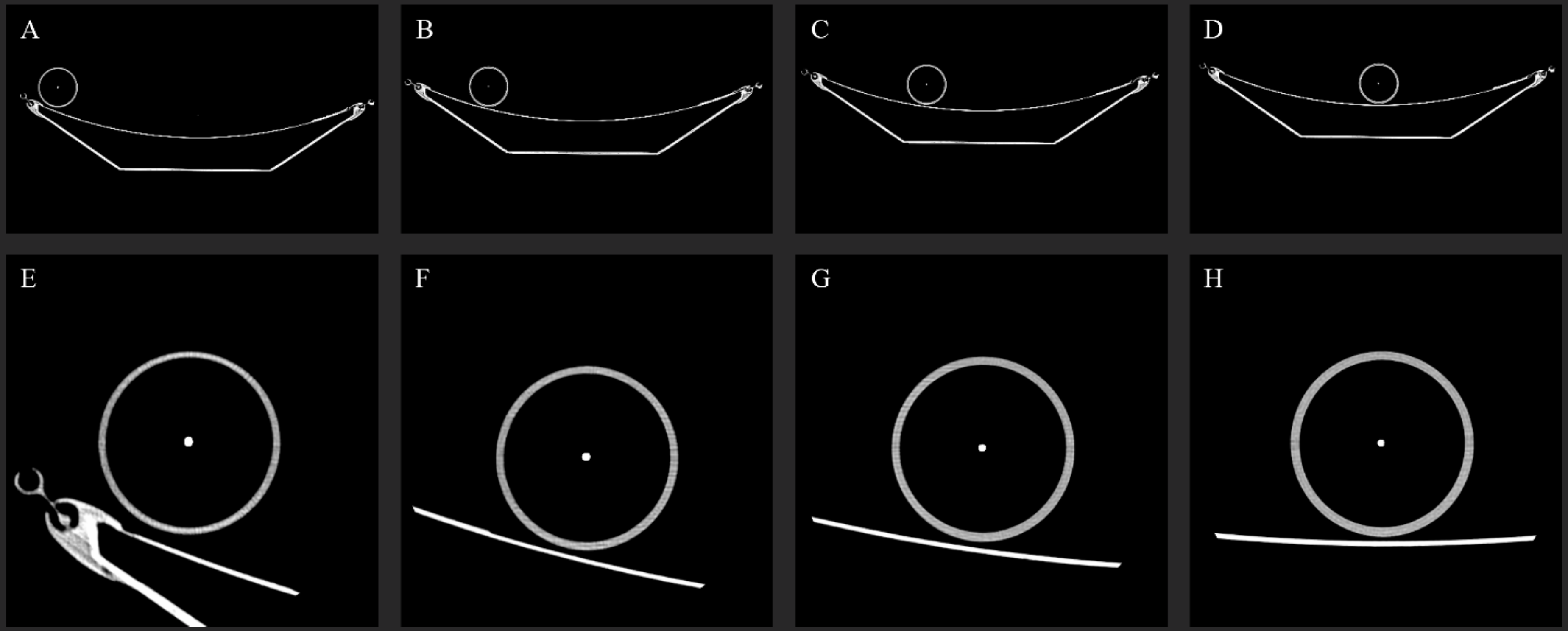


In reality, each view angle represents a finite angular range since the gantry is always moving and data acquisition time is finite

Position and Spatial Resolution



Rubert, N., Szczykutowicz, T., & Ranallo, F. (2016). Improvement in CT image resolution due to the use of focal spot deflection and increased sampling. *Journal of applied clinical medical physics*, *17*(3), 452-466.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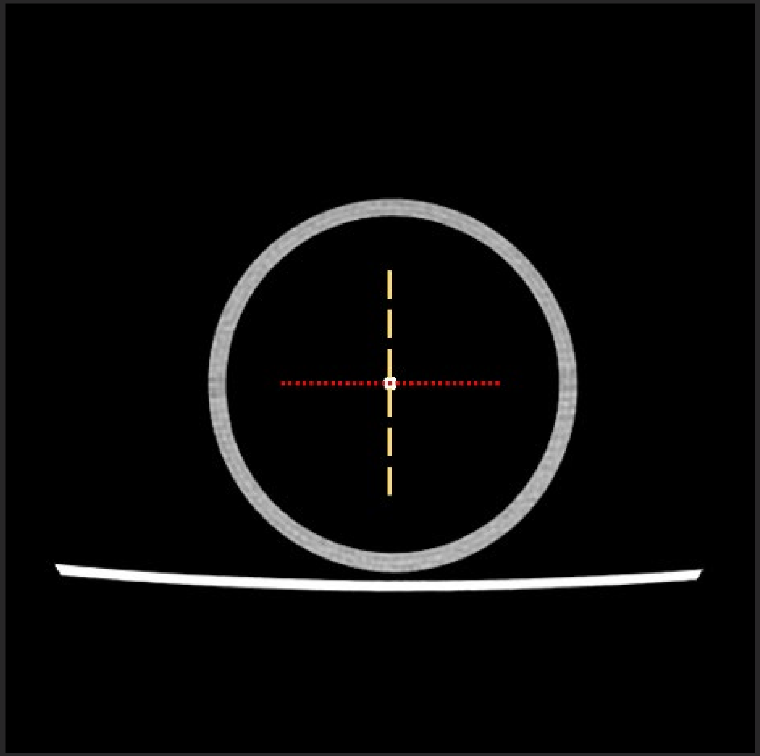
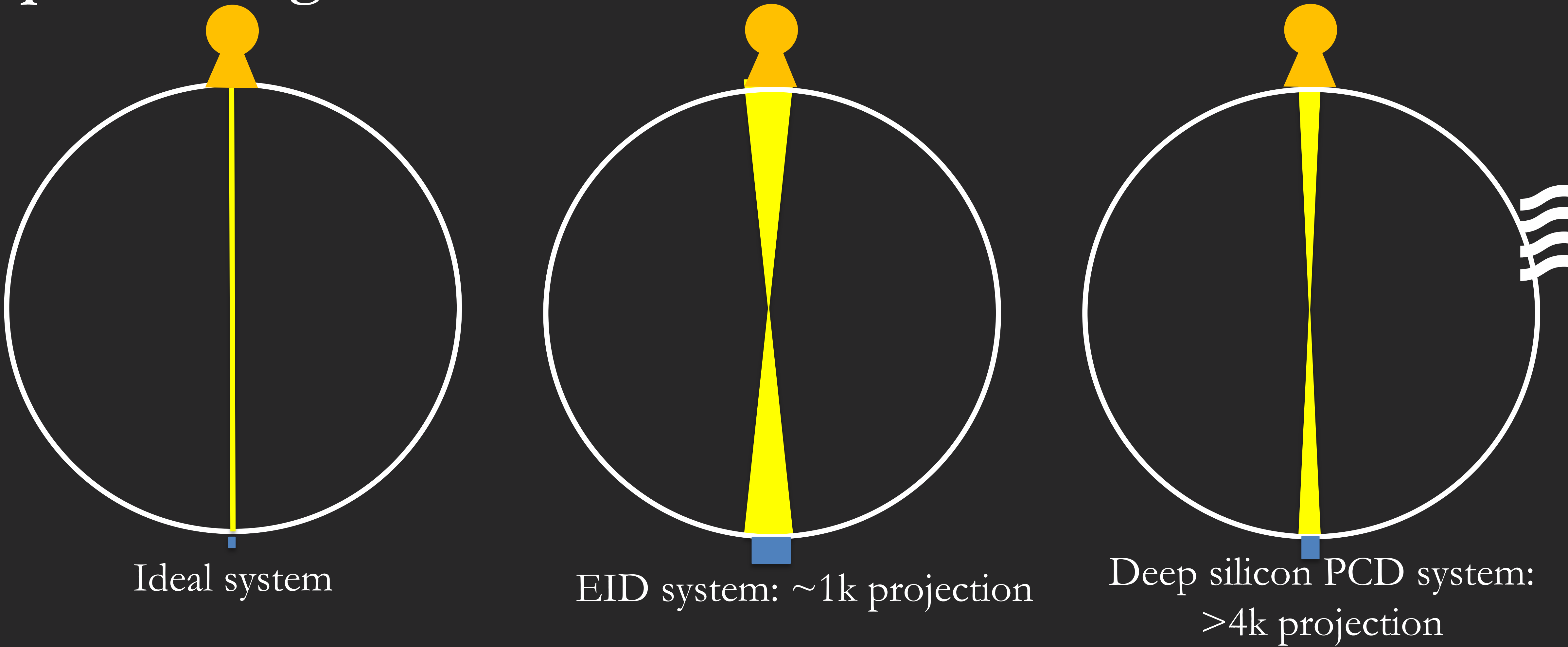


How is spatial resolution affected by patient positioning?

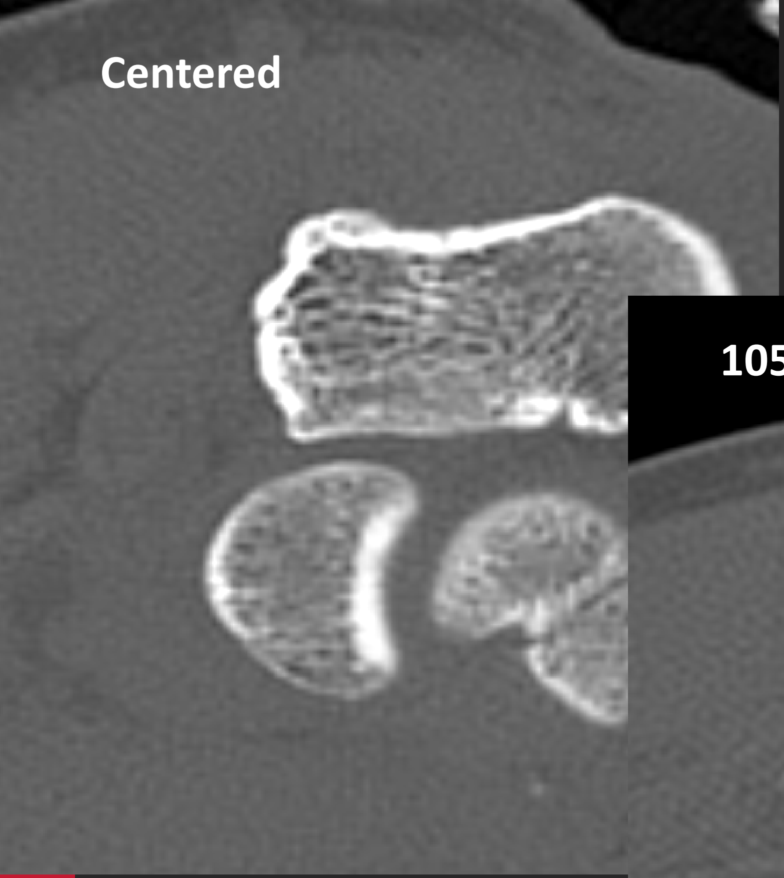


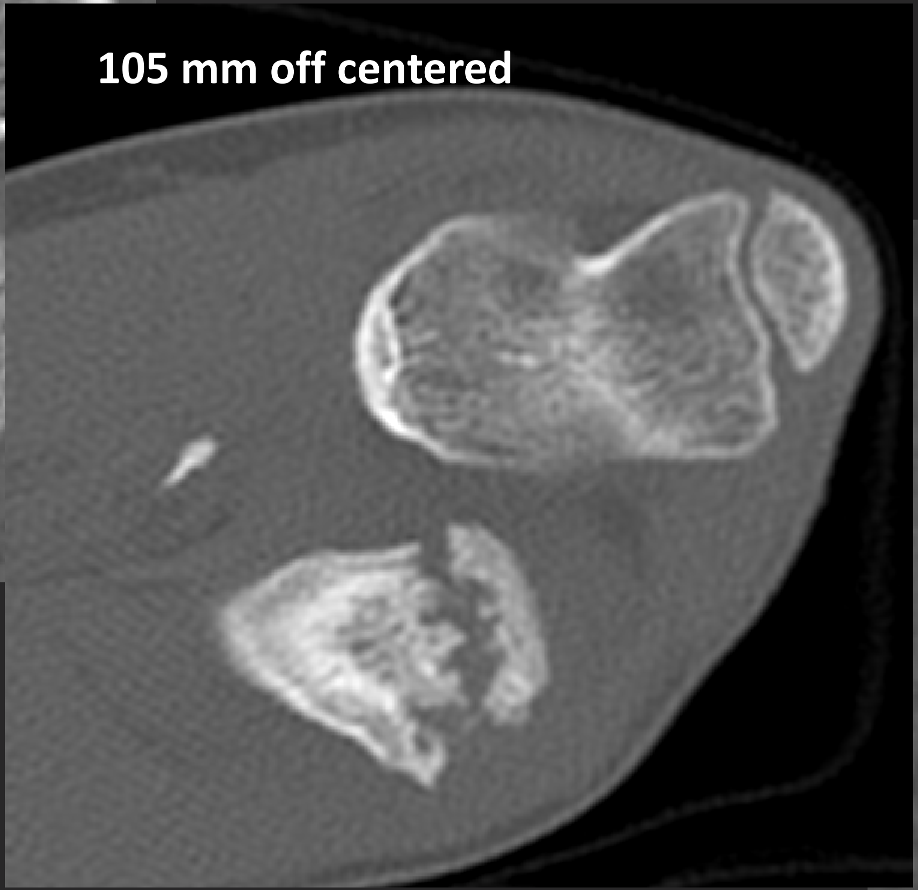
Position	Regular EID			HD EID			PCD		
	Ratio	% Diff	p	Ratio	% Diff	p	Ratio	% Diff	p
AZ 6.7 cm	1.00±0.01	0	0.39	0.99±0.02	1	<.001*	1.00±0.08	0	0.38
AZ 11.8 cm	1.16±0.01	16	<.001*	1.01±0.01	1	<.001*	0.99±0.08	1	0.80
AZ 17.1 cm	1.36 ± 0.01	36	<.001*	1.12 ± 0.01	12	<.001*	0.99 ± 0.08	1	0.82

GE high definition mode is better than regular mode

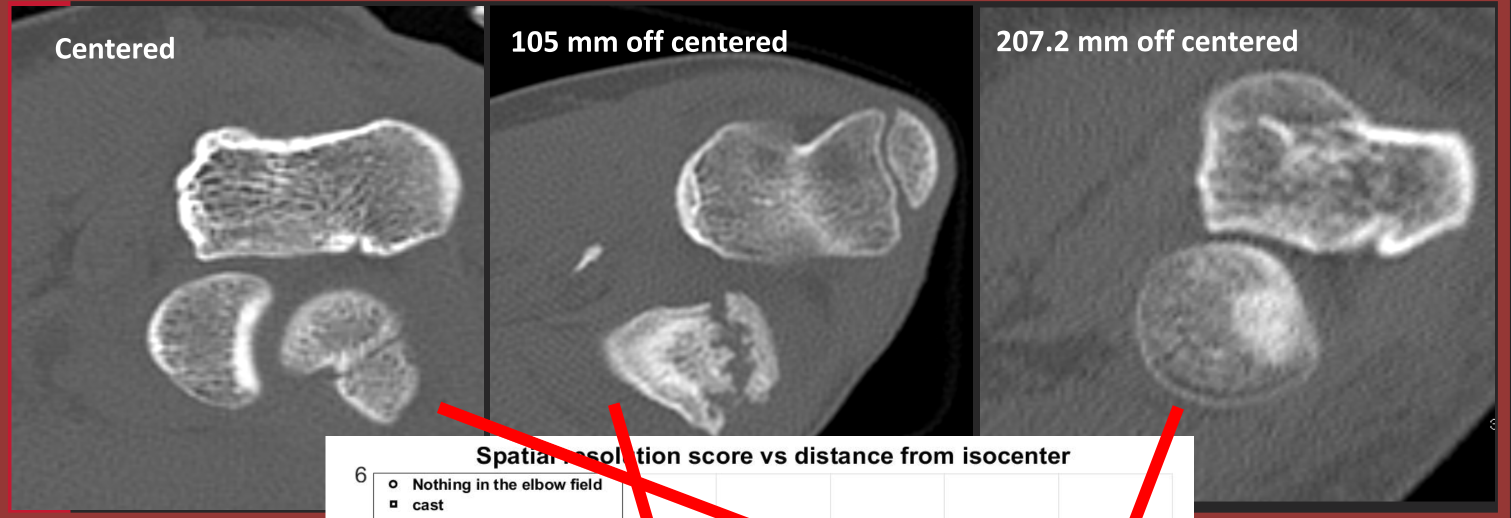
GE Deep Silicon PC is better than HD mode

GE Deep Silicon PC is better than regular mode

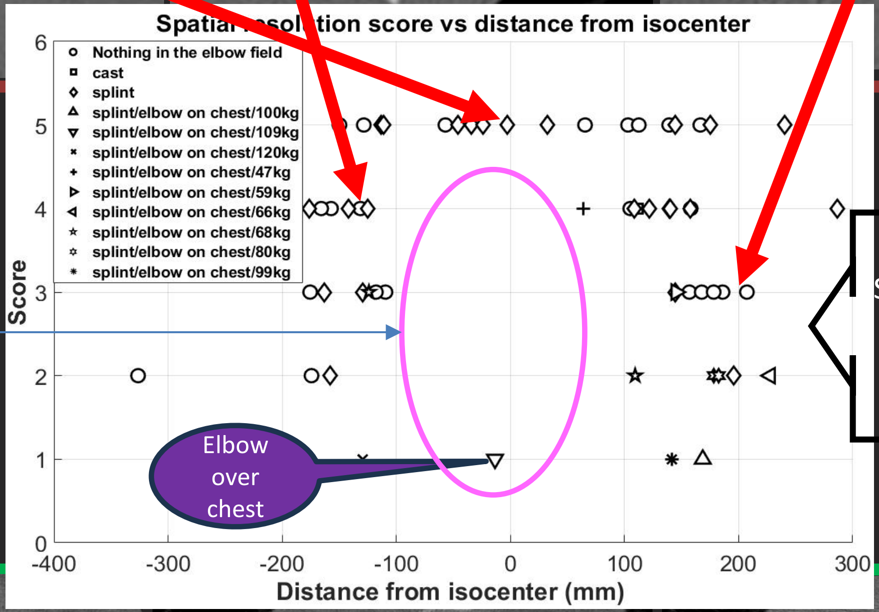

Centered


105 mm off centered


207.2 mm off centered



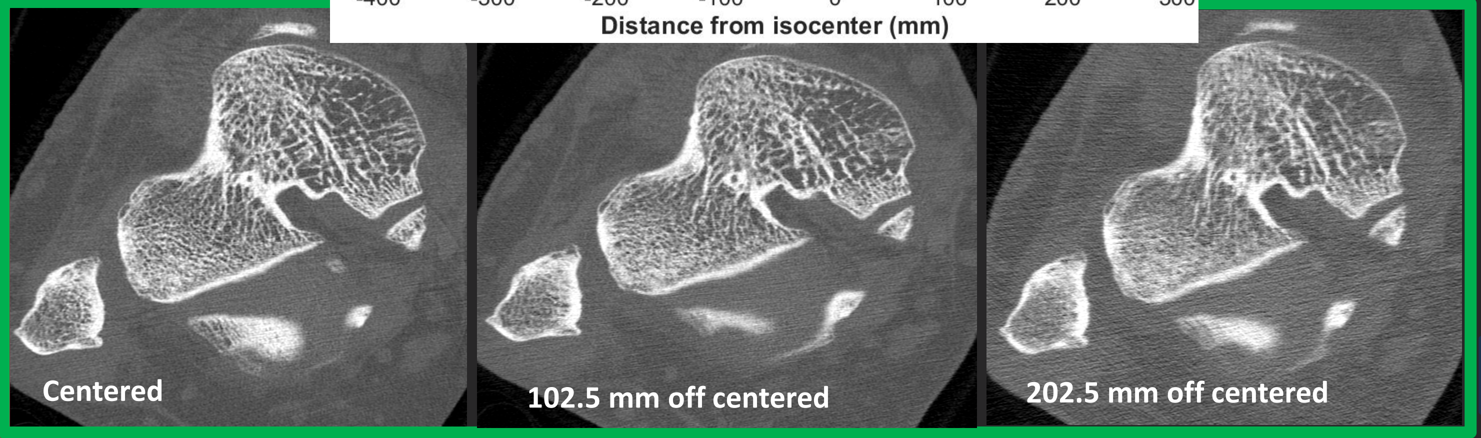
EID CT



“sweet spot” of scanner is evident for EID

Spatial resolution scored by Rads vs distance from isocenter (mm) for EID CT

PCD CT

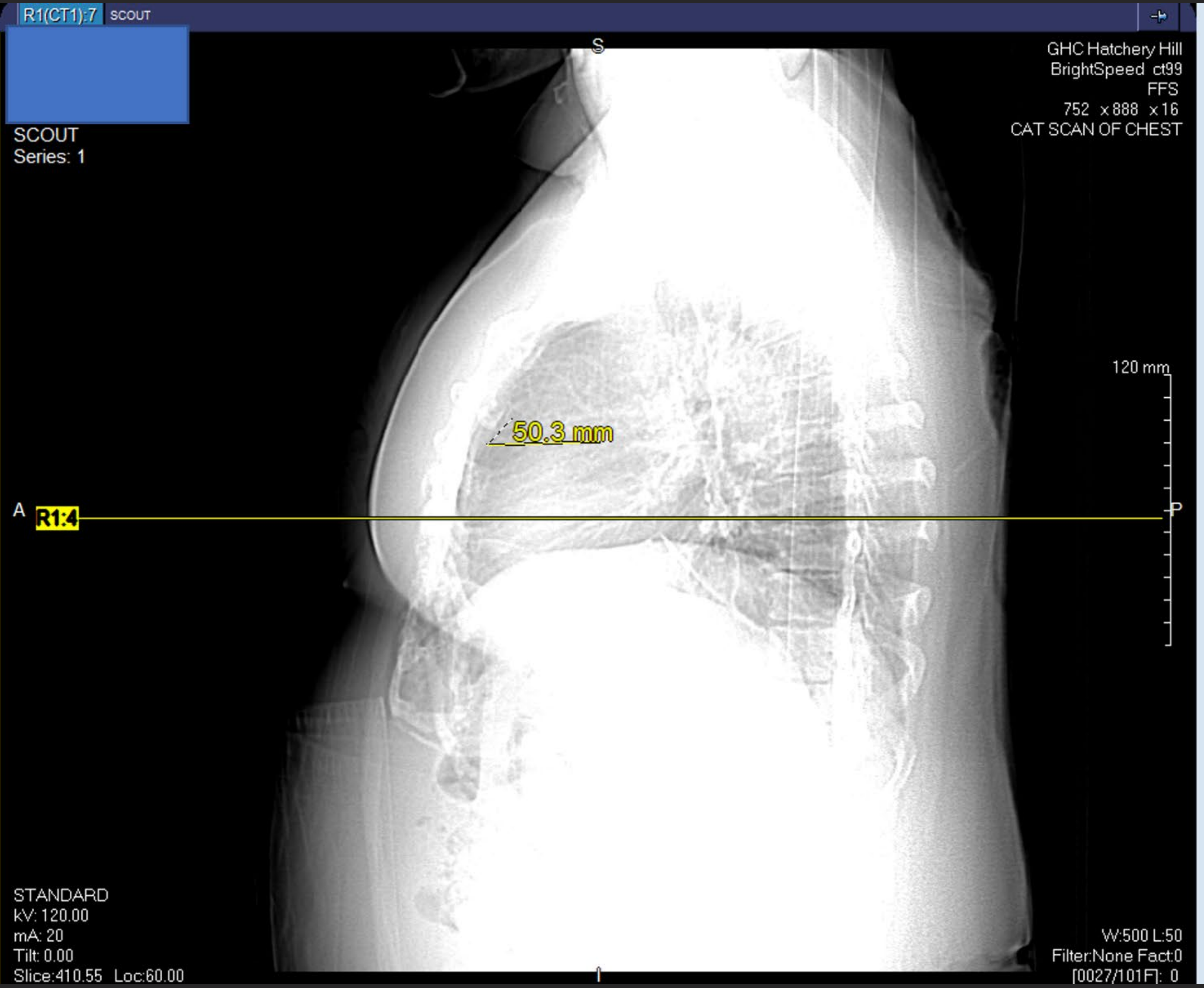


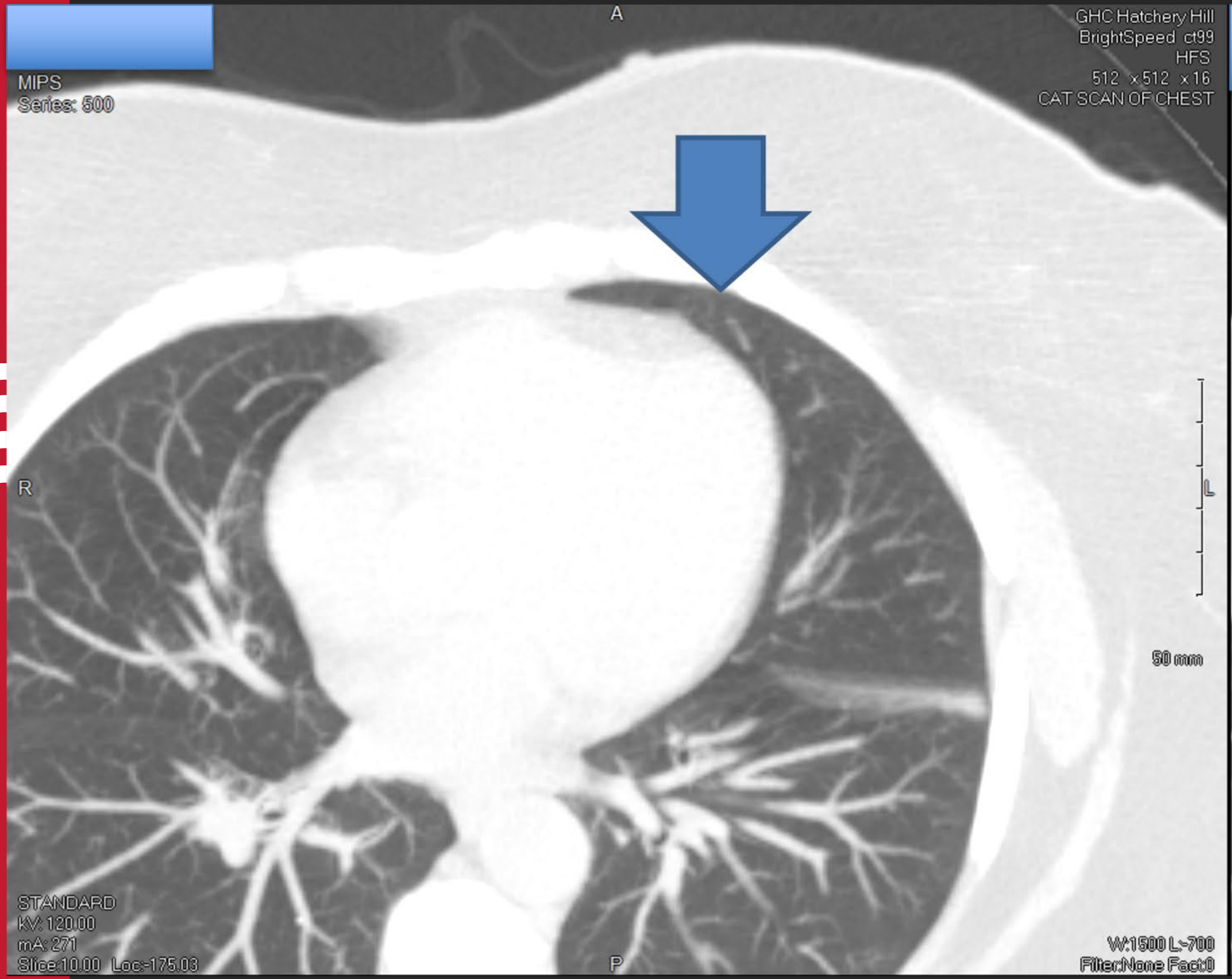
Reader scores not significantly changed with distance from iso-center for Photon Counting

Issues with mis-positioning and spatial resolution: Clinical Example

Anterior portion of lung **far** from iso-center

Anterior portion of lung **close** from iso-center




A
GHC Hatchery Hill
BrightSpeed ct99
HFS
512 x512 x16
CAT SCAN OF CHEST
MIPS
Series: 500
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50 mm
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kV: 120.00
mA: 271
Slice:10.00 Loc:-175.03
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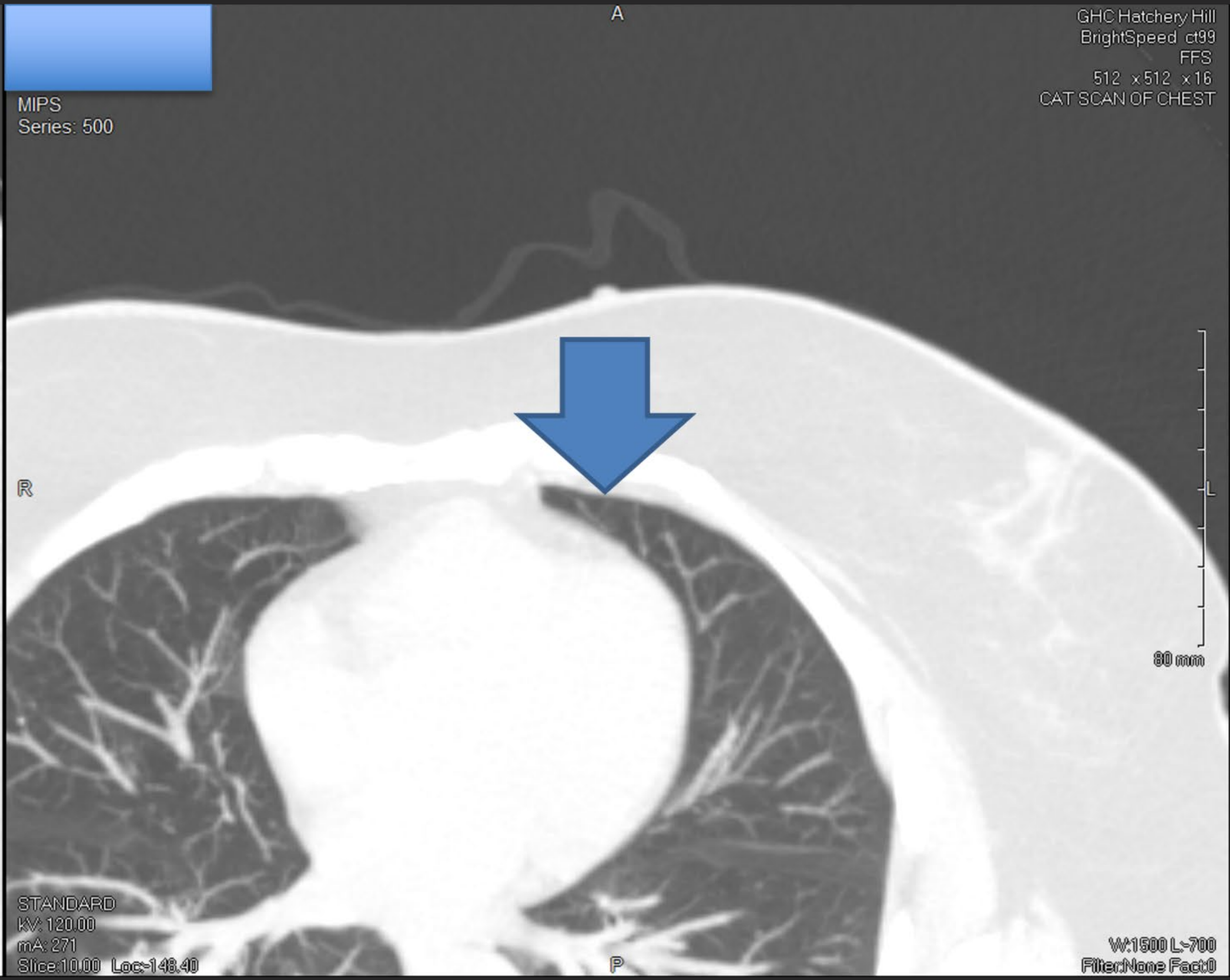
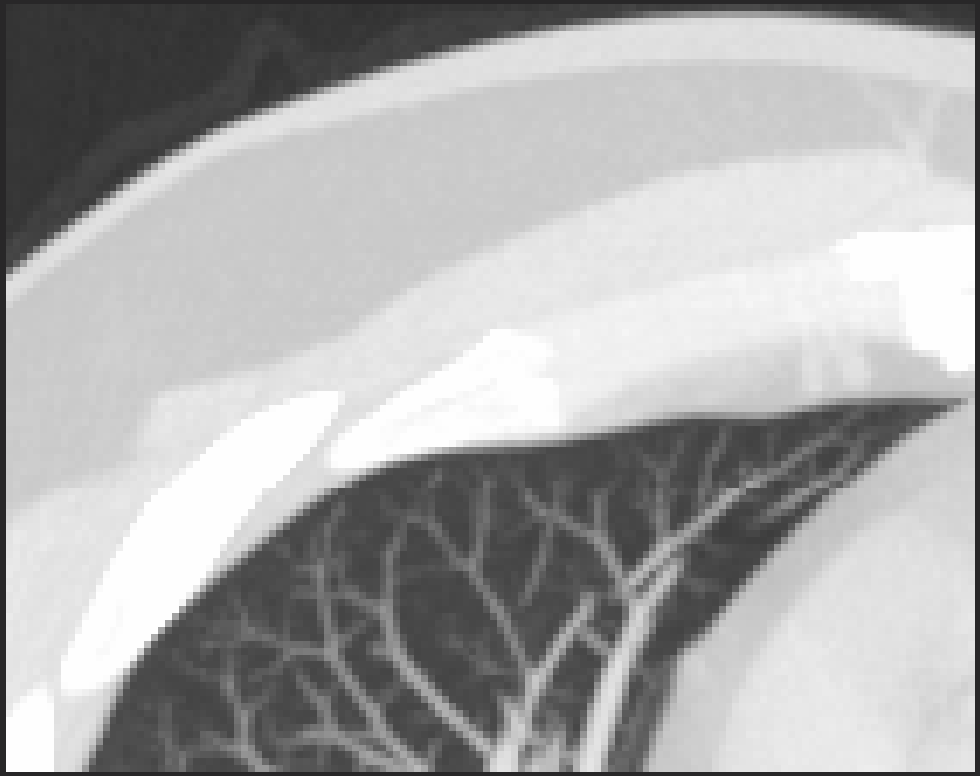
W:1500 L:-700
Filter:None Fact:0


A
GHC Hatchery Hill
BrightSpeed ct99
FFS
512 x512 x16
CAT SCAN OF CHEST
MIPS
Series: 500
R
L
80 mm
STANDARD
kV: 120.00
mA: 271
Slice:10.00 Loc:-148.40
P
W:1500 L:-700
Filter:None Fact:0

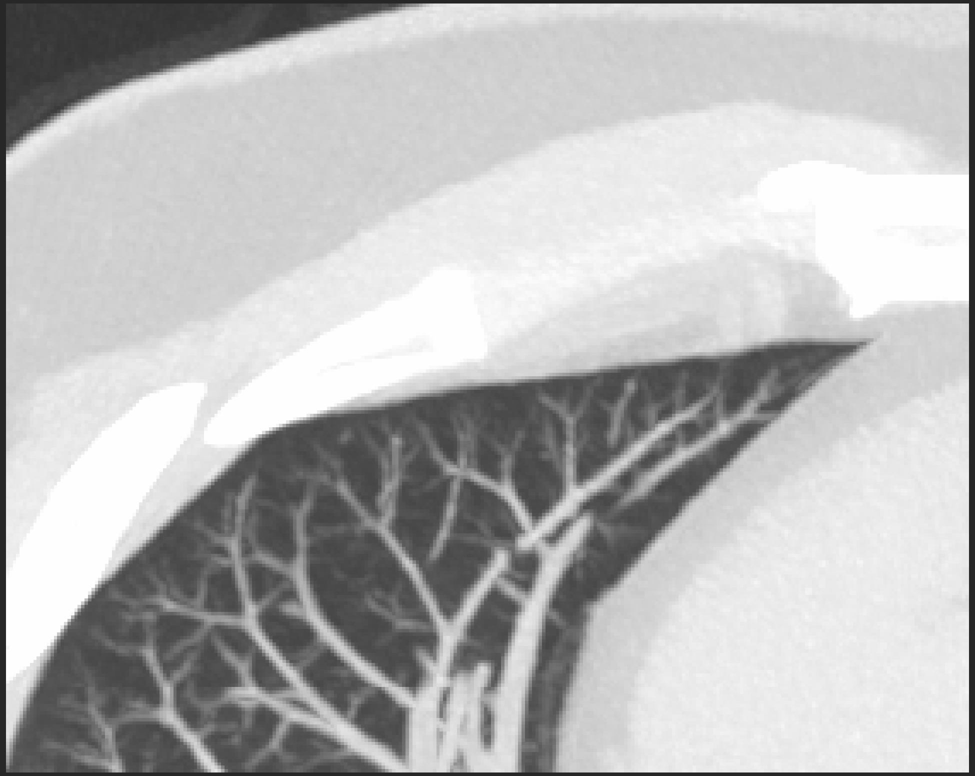
10 mm MIP
14.07 mGy
120 kV
GE standard kernel

EID prior



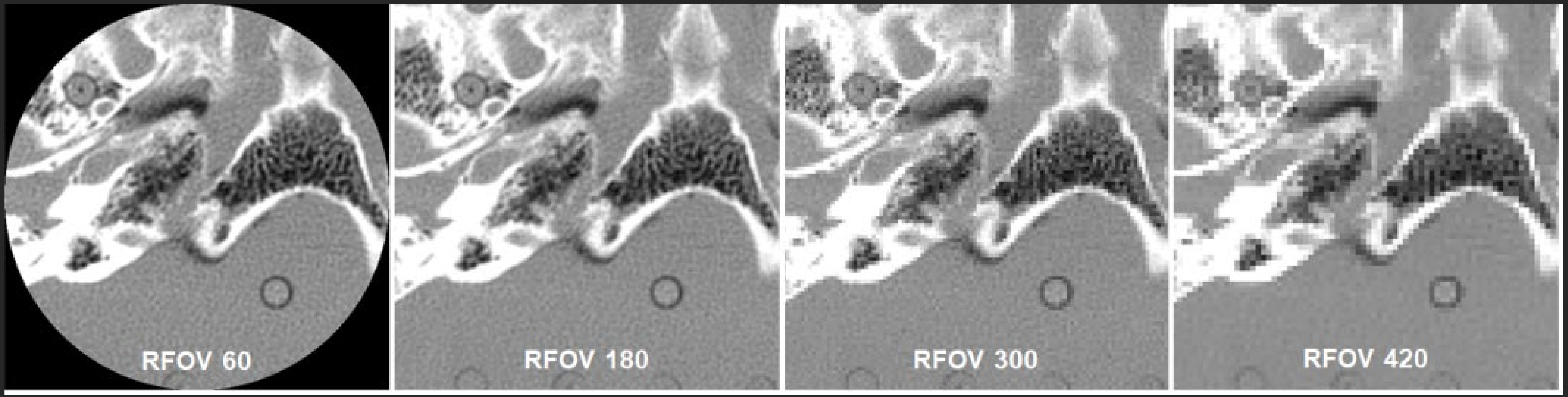
10 mm MIP
14.89 mGy
120 kV
Pluto standard kernel

Deep Silicon

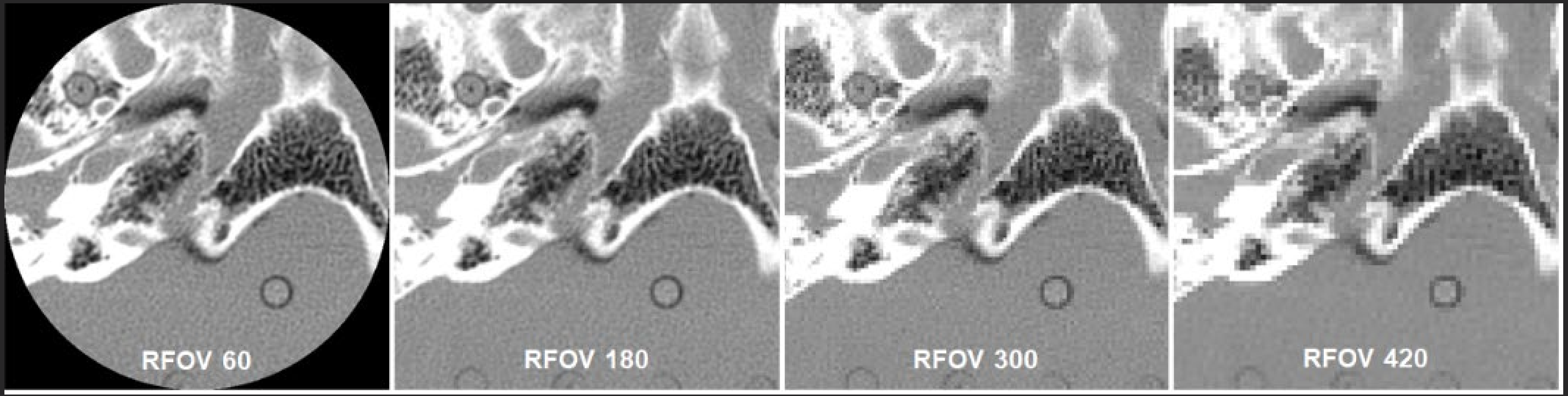


Kernel RFOV mismatch

Same scan data, reconstructed at different field of views, with the same number of pixels



Same scan data, reconstructed at different field of views, with the same number of pixels

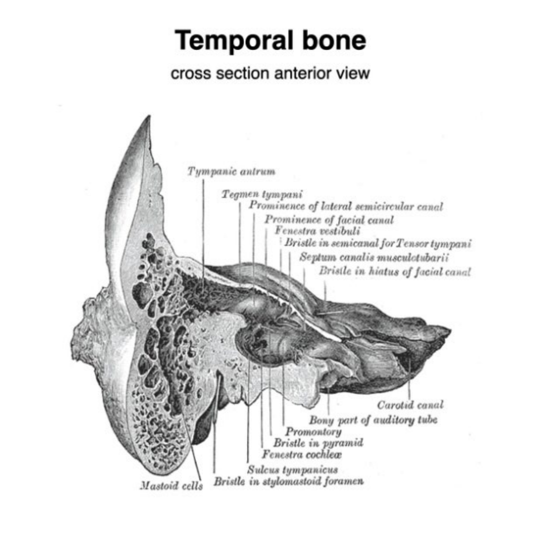


0.12 mm pixel size	0.35 mm pixel size	0.59 mm pixel size	0.82 mm pixel size

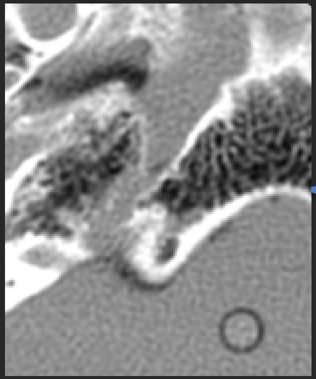
Real object, with infinite spatial frequencies

CT scanner can pass through frequencies up to ~13-20 line pairs for most “high resolution” exams types

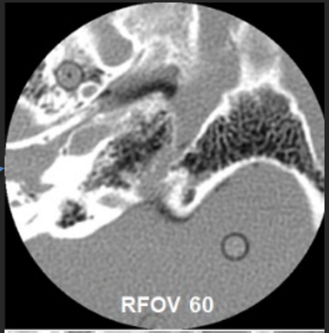
But when depending on how we sample (i.e., display) the image to a radiologist, the resolution can be preserved or lost



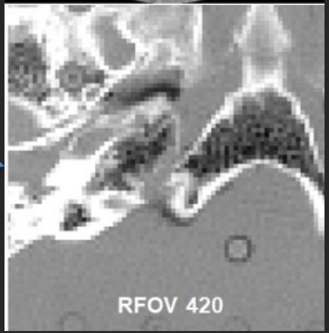
Gray’s

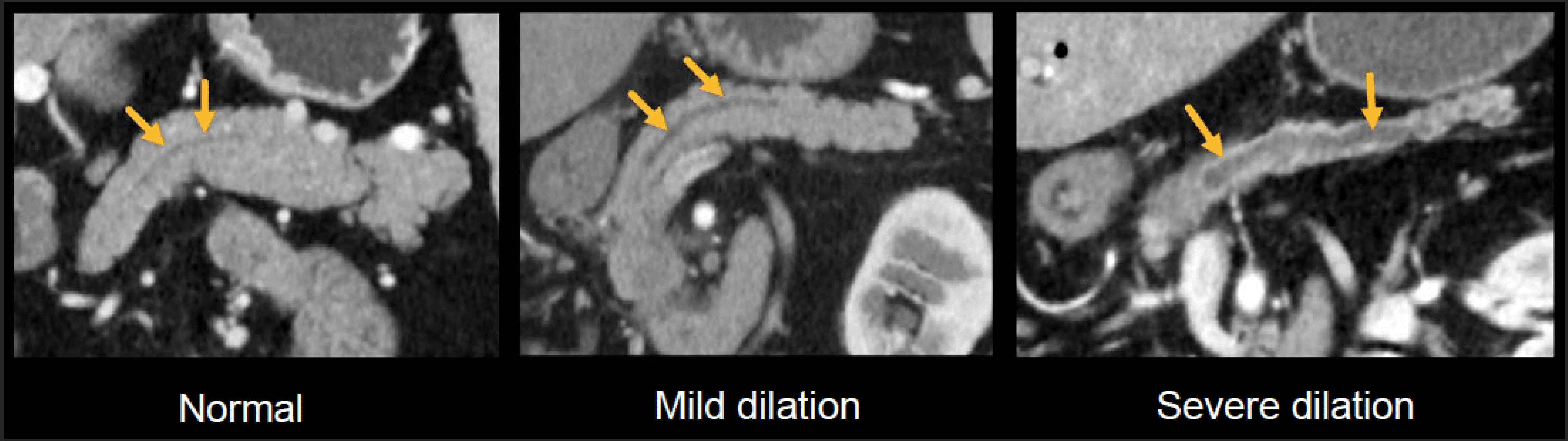


Sampling that preserves what the CT scanner can measure



Sampling that destroys what the CT scanner can measure



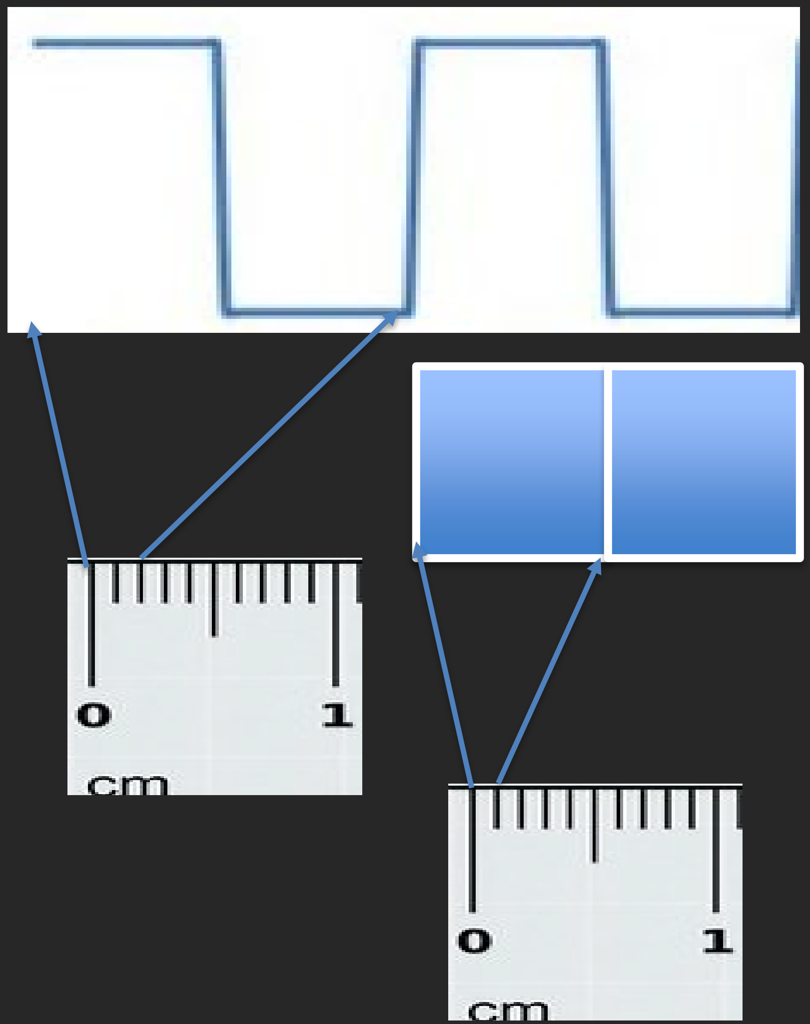


Pancreatic duct varies in width from ~4 to 2 mm from head to tail

This is currently a “hot topic” in photon counting CT, “Can I see this duct with PC CT?”

What kind of pixel matrix would I need to support 2 mm resolution?

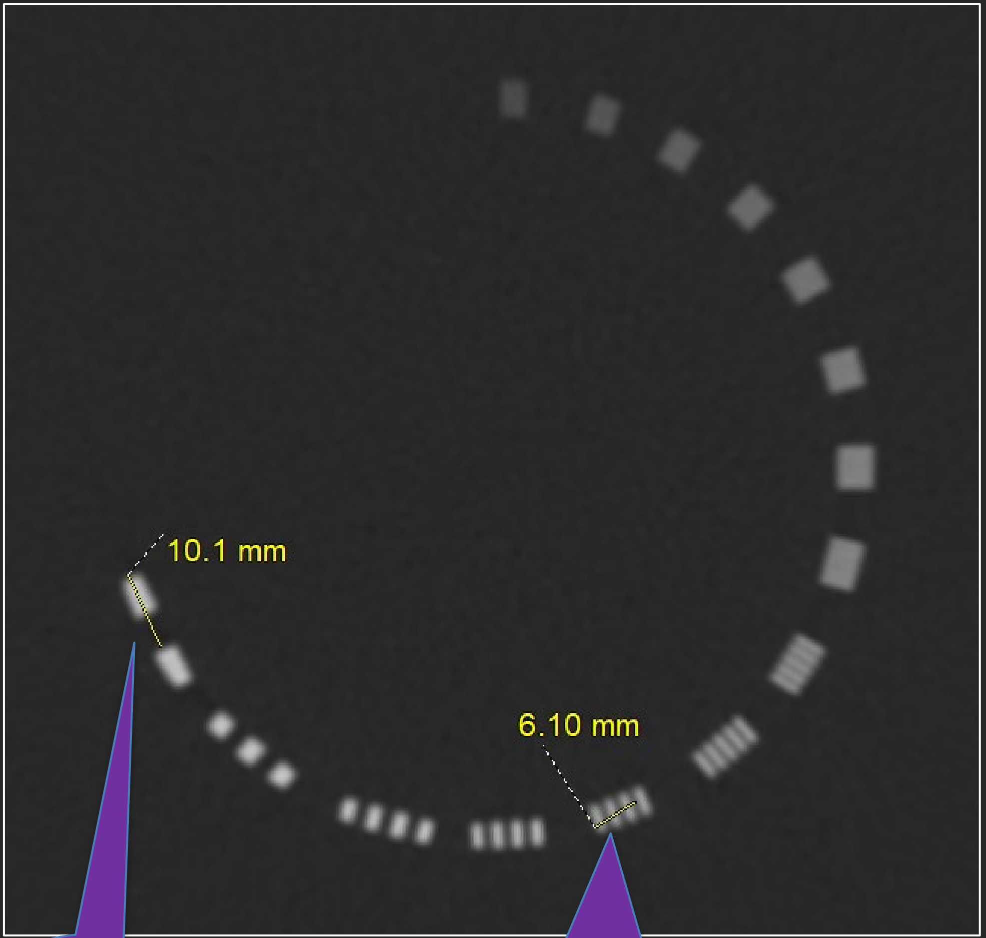
Stolen from https://litfl.com/abdominal-ct-biliary-system-and-pancreas/



1. So we have a function who repeats every 2 mm (2 mm periodicity)

2. Therefore we need to sample this at with pixels with a size ½ the period, to 2x the frequency of the input signal. So each pixel needs to be 1 mm. (This is common sense based on picture above, called Nyquist Sampling Theorem)

For the electrical engineering aficionados among you: this example is illustrative but not strictly correct. A square wave contains many higher-frequency harmonics above its fundamental, which would of course be aliased if we sampled at only twice the fundamental frequency.



1 line pair per cm

5 line pairs per cm (~6 mm measured, containing 3 pairs, that is 2 mm period)

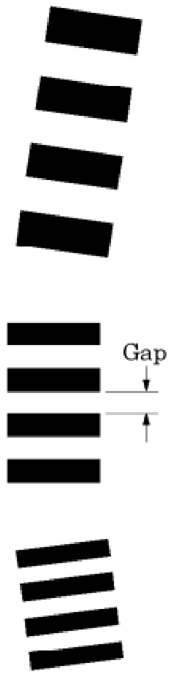
21 Line pair per centimeter high resolution gauge

The 21 line pair/cm gauge has resolution tests for visual evaluation of high resolution ranging from 1 through 21 line pair/cm. The gauge accuracy is ± 0.5 line pair at the 21 line pair test and even better at lower line pair tests.

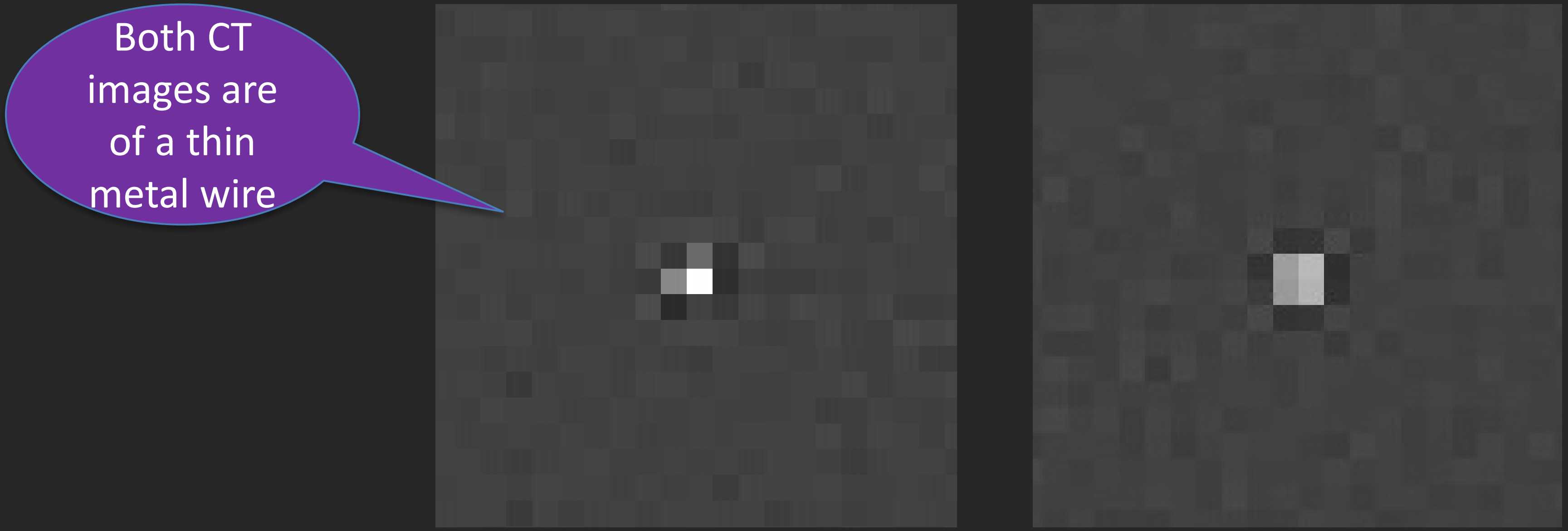
The gauge is cut from 2mm thick aluminum sheets and cast into epoxy. Depending on the choice of slice thickness, the contrast levels will vary due to volume averaging.

Line Pair/cm	Gap Size
1	0.500 cm
2	0.250 cm
3	0.167 cm
4	0.125 cm
5	0.100 cm
6	0.083 cm
7	0.071 cm
8	0.063 cm
9	0.056 cm
10	0.050 cm

Line Pair/cm	Gap Size
11	0.045 cm
12	0.042 cm
13	0.038 cm
14	0.036 cm
15	0.033 cm
16	0.031 cm
17	0.029 cm
18	0.028 cm
19	0.026 cm
20	0.025 cm
21	0.024 cm



When we start to flirt with the Nyquist limit, we get these situations where the specific locations of objects with respect to the pixel matrix matter



- This is all why we do zoomed in reconstructions for temporal bone
- This is why we do zoomed in reconstructions for spines
- This is why it doesn’t make sense thoracic rads like “chest” kernels on full RFOV lung images…

Page | Discussion | Read | Edit | View history

CT1 Temporal Bone 2.11

Protocols

UWHC TOC
UWHC Ped TOC
EMC/EMH TOC
EMC/EMH PED TOC
Community TOC
Community PED TOC
PETCT/Ablation/Biopsy
3D Lab TOC

Tech Resources

Contents [hide]

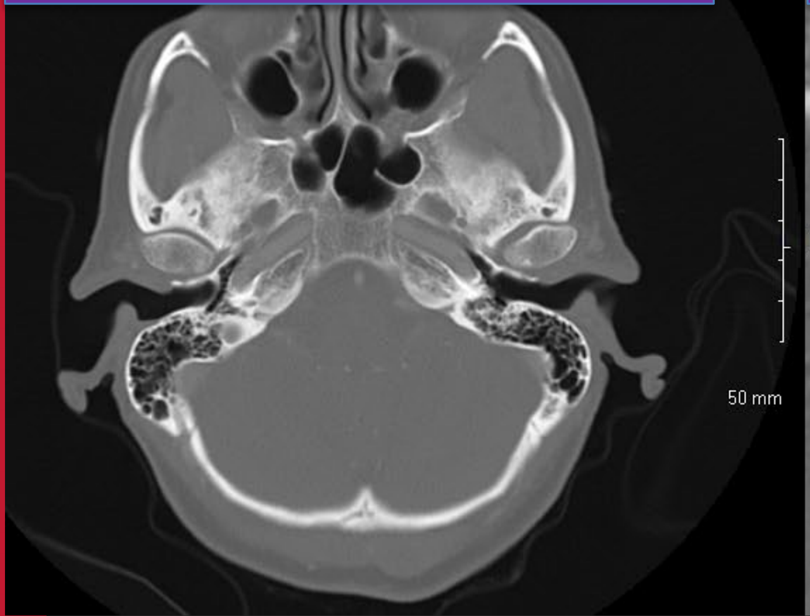
Recon 1 (BONE)

DFOV	22
Recon Type	Bone Plus
WW/WL	2500/350
Recon Option	Plus
Recon Option	
ASiR/ASiR256/DLIR	None
Slice Thickness (mm)	2.5
Interval (mm)	1.5

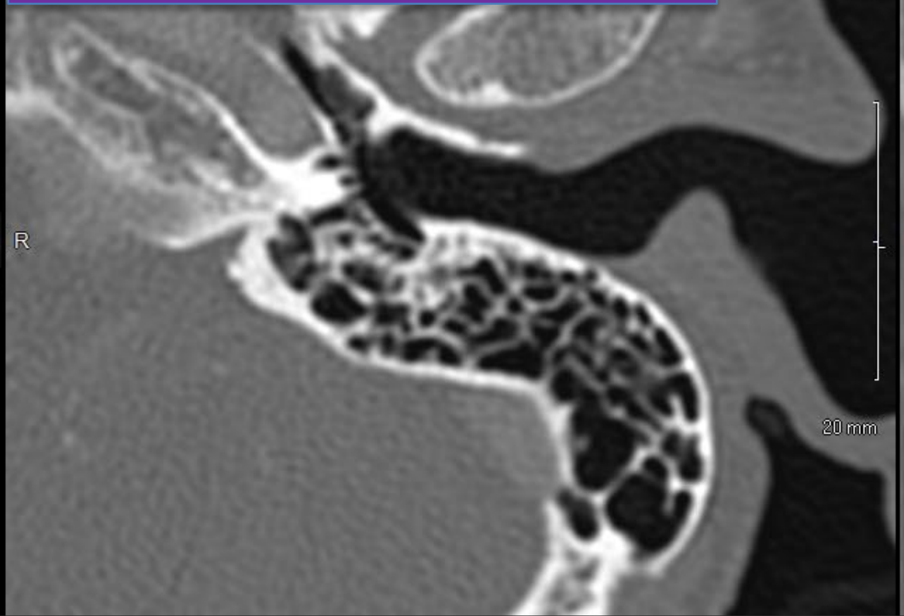
Recon 2 (THIN BONE RT)

DFOV	9.6
Recon Type	Bone Plus
WW/WL	2500/350
Recon Option	Plus
Recon Option	IQ Enhance
ASiR/ASiR256/DLIR	None
Slice Thickness (mm)	0.625
Interval (mm)	0.312

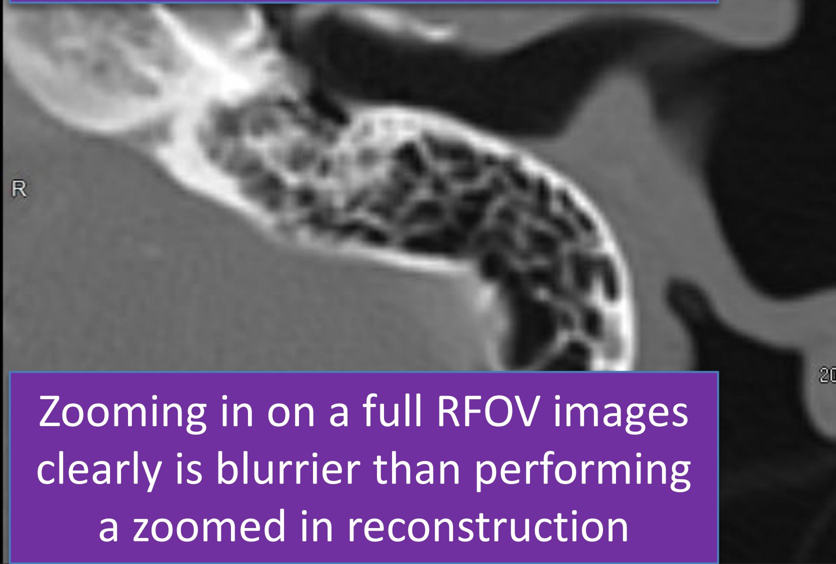
Full RFOV high resolution head



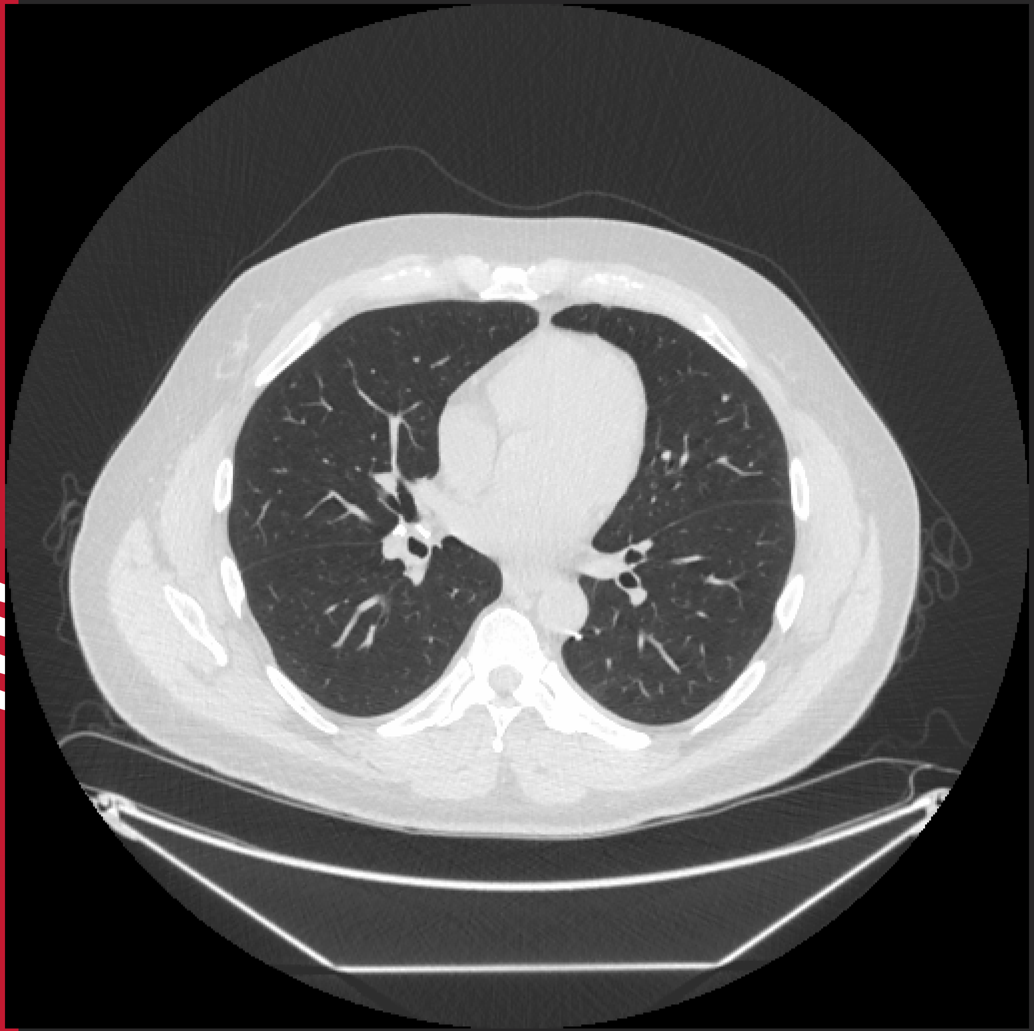
Zoomed in reconstruction (9.6 cm) high resolution head



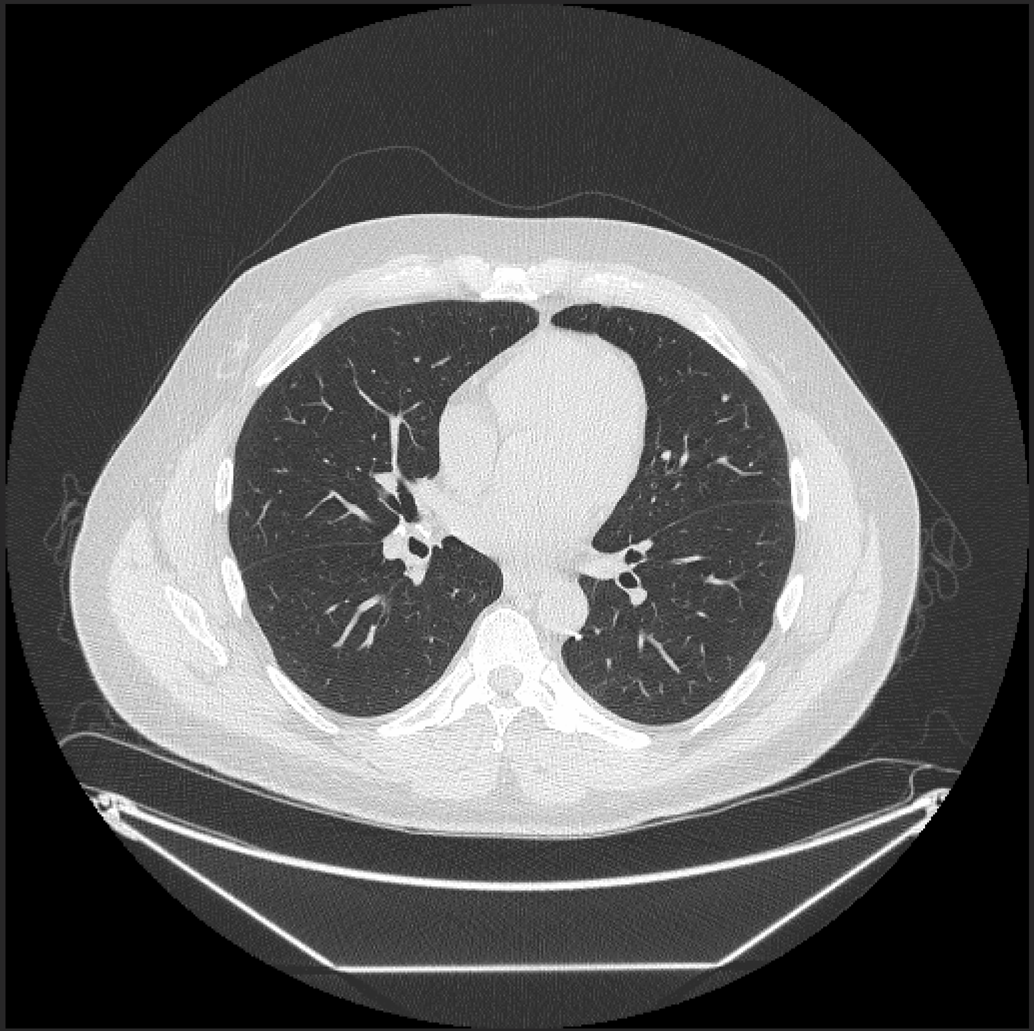
Full RFOV high resolution head zoomed in to match a zoomed in reconstruction



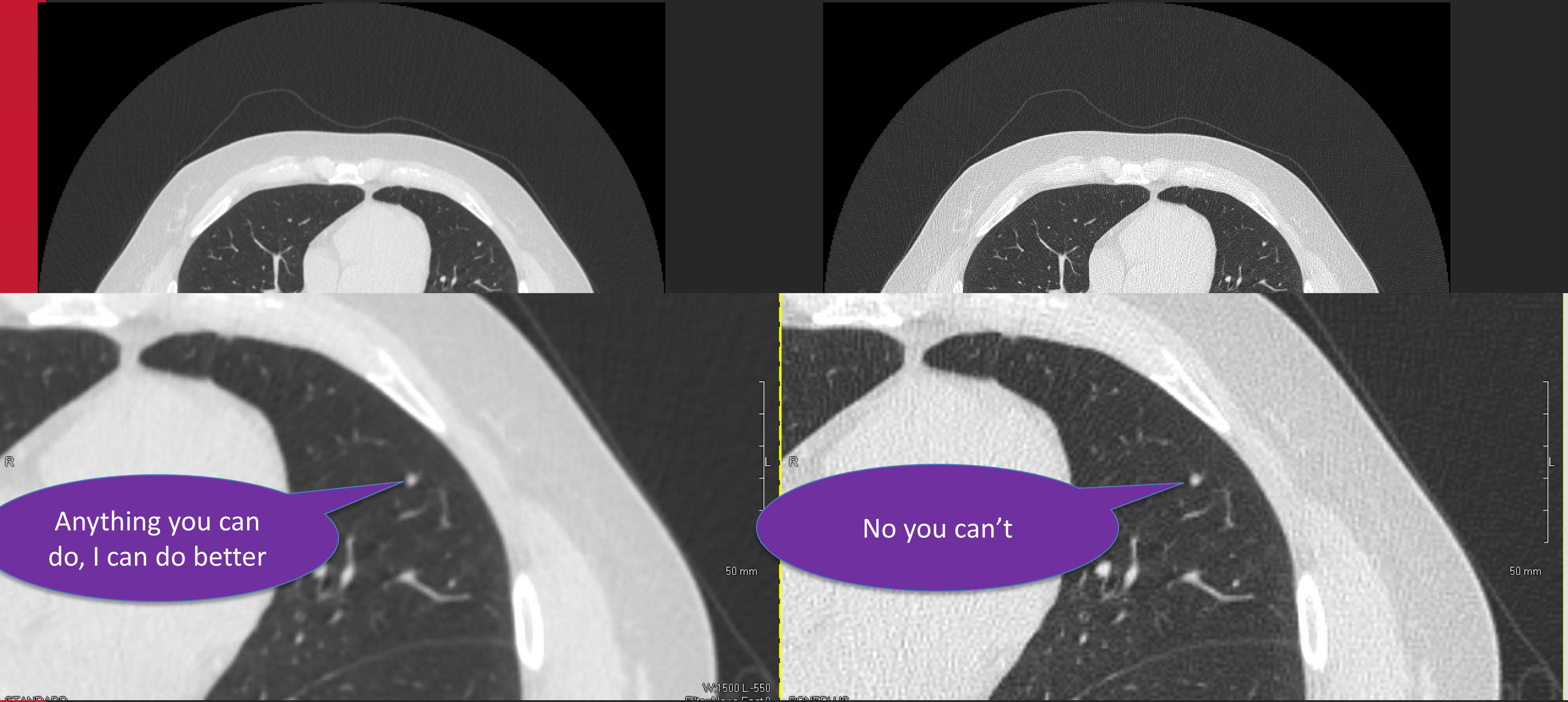
Zooming in on a full RFOV images clearly is blurrier than performing a zoomed in reconstruction



500 mm RFOV 512 pixels soft tissue kernel



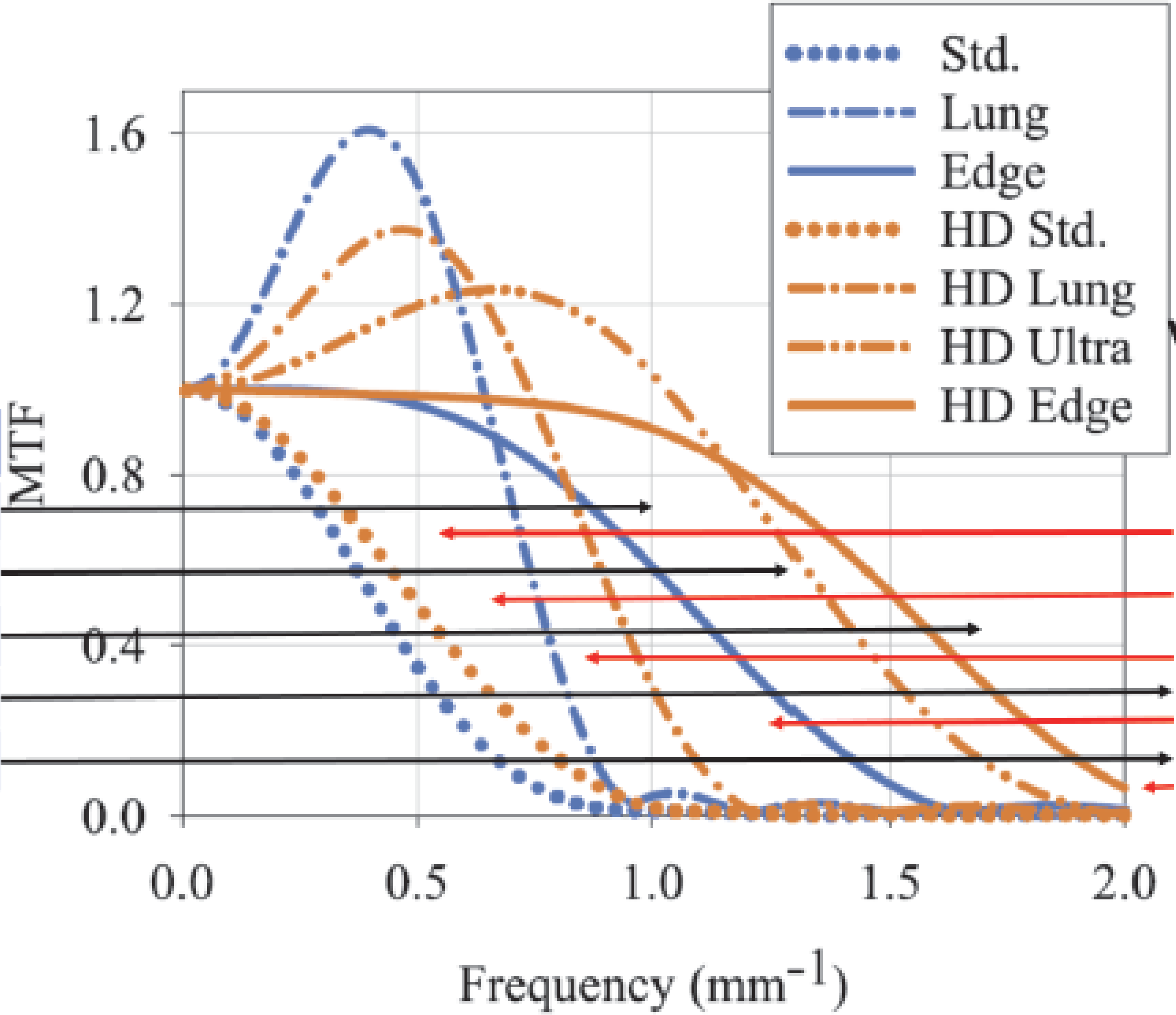
500 mm RFOV 512 pixels high resolution kernel



The only benefit we get from high resolution kernel at this RFOV is noise and aliasing

Voxel limiting RFOV
 # pixels/(2*RFOV)

1024 pixel Image	
500 mm	1.02 lp/mm
400 mm	1.28 lp/mm
300 mm	1.71 lp/mm
200 mm	2.56 lp/mm
100 mm	5.12 lp/mm



Voxel limiting RFOV
 # pixels/(2*RFOV)

512 pixel Image	
500 mm	0.51 lp/mm
400 mm	0.64 lp/mm
300 mm	0.85 lp/mm
200 mm	1.28 lp/mm
100 mm	2.56 lp/mm

From Tim Stick's CT Handbook

CTECC
CT EDUCATION AND COLLABORATION CENTER

Thanks!

Feel free to contact me at tszczykutowicz@uwhealth.org